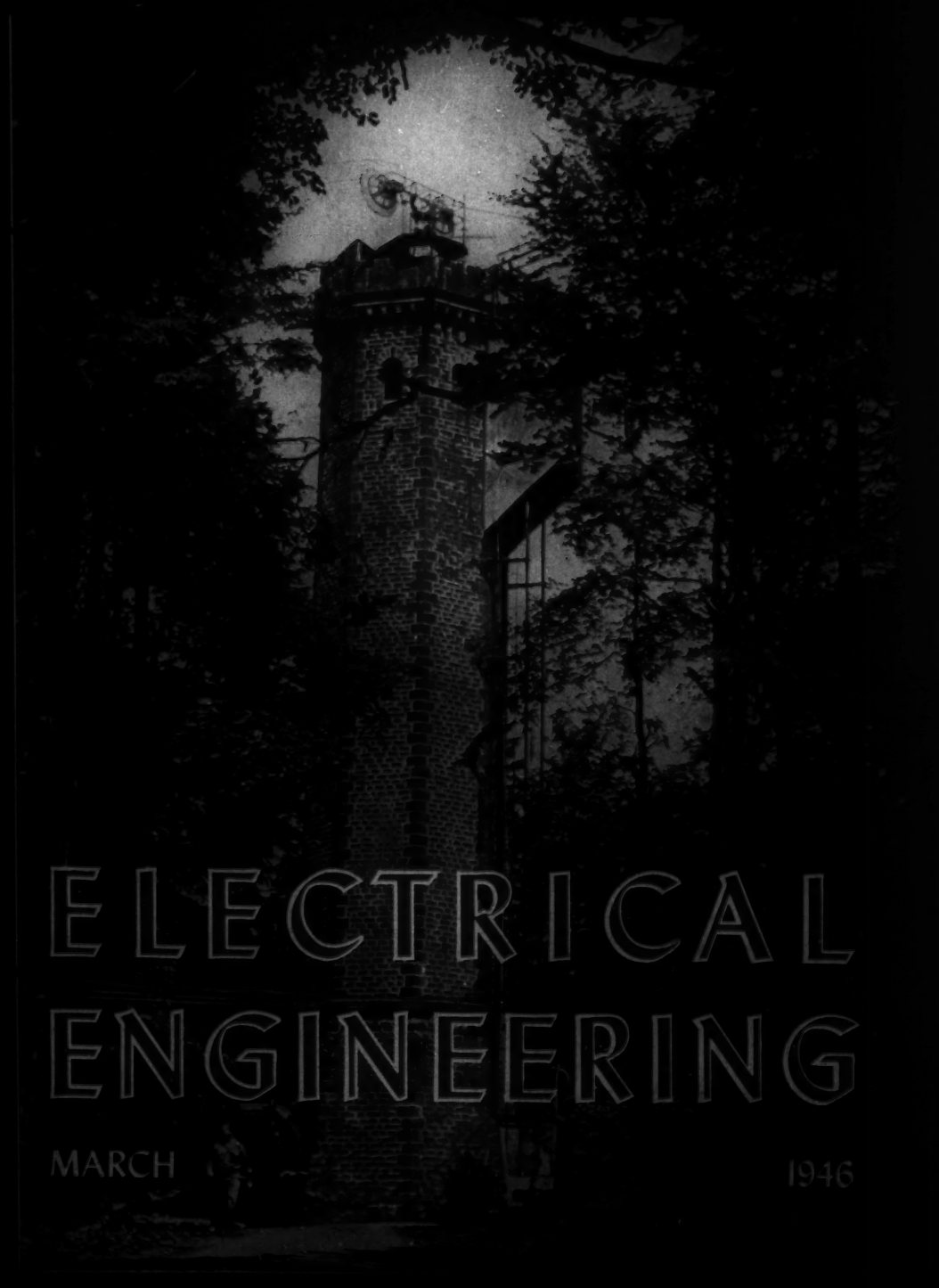
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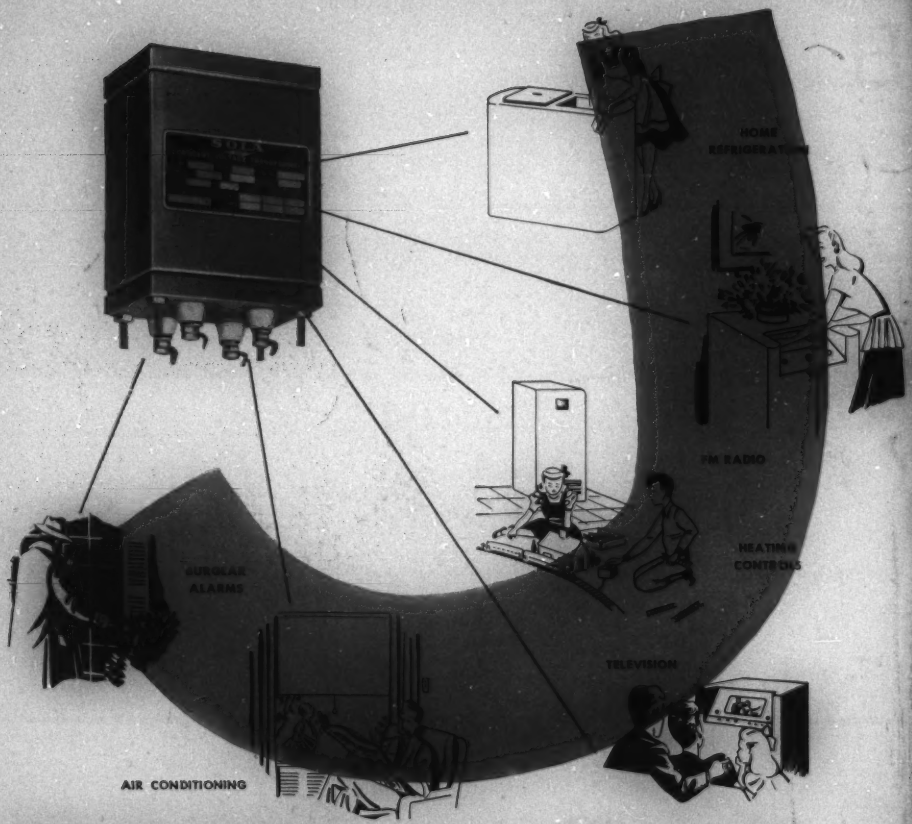

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MARCH
1946

Cover: Terminal of microwave radio relay system at Heidelberg, Germany — Bell Laboratories photo

Communications: Implement to Peace — Ray C. Wakefield . . . 99

Centralized Power Generation — Philip Sporn . . . 105

Progress in Nuclear Physics
I. "Nuclear Disintegrations" . . . 108
II. Review of Basic Concepts . . . 110
III. Chronology of Bomb Research . . . 113

Statistical Methods in Quality Control—X — AIEE Subcommittee . . . 117

Miscellaneous Short Item:
Testing Gauge, 119

Institute Activities . . . 120

Of Current Interest . . . 139

TRANSACTIONS SECTION

(Follows EE page 144; a preprint of pages 97–176 of the 1946 volume. Any discussion of these papers will appear in the June 1946 "Supplement to Electrical Engineering—Transactions Section" and in the 1946 volume.)

Arc Starting Characteristics of D-C Welders — Joseph M. Tyrner . . . 97

Stress Measurement — Robert E. Kern, Sidney B. Williams . . . 100

Linear Couplers — E. L. Harder, E. H. Klemmer, R. E. Neidig . . . 107

Long 60-Cycle Arcs in Air — A. P. Strom . . . 113

Industrial Application of Rototrol Regulators — W. R. Harris . . . 118

Thermal-Demand-Meter Testing Techniques — E. E. Lynch, M. E. Douglass . . . 124

Electric Drive for Calender Train — K. W. John, G. W. Knapp, W. A. Mosteller . . . 128

Crystal Channel Filter for Broad Band Carrier Systems — E. S. Willis . . . 134

Die Cast Rotor Testing by Test Stator Method — P. H. Trickey . . . 139

Series Capacitor Protective Device — R. E. Marbury, J. B. Owens . . . 142

B-H Curve Tracer for Magnetic-Recording Wire — T. H. Long, G. D. McMullen . . . 146

Automatic Oscillograph With a Memory — A. M. Zarem . . . 150

Capacitor Discharge Welding Transformers — T. W. Dietz, G. M. Stein . . . 154

Phonograph Reproducer Design — W. S. Bachman . . . 159

Testing of Hydroelectric Units — G. D. Floyd, J. J. Traill . . . 163

Dielectric Recovery by an A-C Arc in an Air Blast — T. E. Browne, Jr. . . . 169

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Statements and opinions given in articles and papers appearing in *Electrical Engineering* are the expressions of contributors, for which the Institute assumes no responsibility. ¶ Correspondence is invited on all controversial matters.

Published Monthly by the

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Founded 1884

VOLUME 65
NUMBER 3

WILLIAM E. WICKENDEN, President — H. H. HENLINE, Secretary

PUBLICATION COMMITTEE: C. F. Wagner, *chairman*; M. S. Coover; H. H. Henline; B. M. Jones; John Mills; J. J. Orr; H. H. Race; G. A. Van Brunt

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HIGHLIGHTS.....

Winter Convention. With a verified total registration of 2,624 the 1946 winter convention set a new attendance record by a margin of more than 35 per cent. The reports given in this issue reflect the convention high lights, including the salient features of the several conferences and the principal actions taken at the various committee meetings. This was the first AIEE convention at which session attendance was strictly limited to persons wearing the convention-registration badge. Also, the $2.00 nonmember registration fee was required. The results of these control measures were highly successful, and well justified the extra effort put forth by committee personnel in policing the entrances to meeting rooms (*pages 122–3*).

District Meetings. Two District meetings are scheduled for the month of April: The South West District meeting at San Antonio, Texas, April 16–18; and the North Eastern District meeting at Buffalo, N. Y., April 24–26. Advance program details are given for the San Antonio meeting (*pages 120–1*). Program details for the Buffalo meeting are scheduled for publication in the April issue of *Electrical Engineering*.

Nuclear Research Reviewed. A tripartite staff report reflects the prophetic 1940 winter convention address of Dr. Enrico Fermi of Columbia University, presents a brief review of some of the basic concepts which underlay and were proved by concentrated wartime research, and presents a chronology of selected high lights of the wartime atomic bomb project. This is preliminary to the scheduled early publication of 1946 winter convention addresses concerning present understandings of the possibilities of the newly found nuclear energy (*pages 108–16*).

World-Wide Communications. Communications can play an important role in co-operation and mutual understanding between nations, the qualities which promote peace. Developments during World War II have solved or have pointed the way to the solution of most of the technical problems entailed by an international communication system. Will the obstacles provided by diplomacy and politics be overcome as easily (*pages 99–105*)?

Series Capacitor Protection. A series capacitor is protected best from overvoltage during fault by a gap having low arc drop with no tendency to cutoff. A new type of by-pass switch automatically by-passes the gap and series capacitor and removes the by-pass after the fault has cleared. The device is used in combination with a special design of graphite gap with self-centering arc characteristics (*Transactions pages 142–6*).

Stress Measurement. A large portion of current strength testing of finished products is accomplished by means of resistance measurements on fine-wire filaments bonded to the surface of the test element. To use such a gauge most effectively the tester should know the product designer's problem and some of his methods of gauge data analysis as well as be familiar with gauge installation, operation, and circuit theory (*Transactions pages 100–07*).

Linear Couplers. A new protective system employing linear couplers, or air-core mutual reactors, was installed for the protection of 114-kv busses at York and Middletown, Pa. The tests made on this pioneer installation are interpreted and the field of application is discussed (*Transactions pages 107–13*).

Meter Testing. With the increasing use of thermal meters testing methods more nearly resembling those of the mechanical type will be desired. Former techniques which were particularly applicable to thermal meters consumed a considerable amount of time but shorter testing methods can be devised (*Transactions pages 124–8*).

Quality Control. The quality of most electric equipment cannot be judged by the simple per-cent-defective method because of the many characteristics involved. In the current article of the statistical series a method of rating is considered which recognizes differences in the seriousness of defects, and makes use of a system of weighting them accordingly (*pages 117–19*).

News 120

South West District Meeting 120
Winter Convention 122
North Eastern District Meeting 122
Edison Medalist 124
Hoover Medalist 125
Engineers' Reading List 139
Future Meetings
AIEE 130
Other Societies 142
Personal Items 130
Membership 137
Letters to the Editor 142
New Books 144
Pamphlets 144

Co-ordinated Electric Drive. A co-ordinated electric drive has been developed which is more successful than a mechanical drive in such processes as the coating of fabrics with rubber. The new electric drive employs amplidyne as well as electronic control (*Transactions pages 128–34*).

Automatic Oscillograph. The persistence of fluorescence, a characteristic of cathode-ray tube screens, is utilized to obtain electrical memory on an instrument which can record automatically electrical conditions before, during, and after a transient. One example of its use is the recording of transients which may occur during the operation of a mercury-arc polyphase converter (*Transactions pages 150–4*).

Rototrol Regulators. The Rototrol is a simple and reliable regulator which is finding increasing application in industry. Its fundamental theory, application of circuits most commonly used, and operating results for typical installations are discussed (*Transactions pages 118–23*).

Testing of Hydroelectric Units. The application of the "AIEE Test Code for Synchronous Machines" to acceptance testing of hydraulic-type generators is analyzed. The methods of testing given in the code which can be used are outlined and reasons are given why other methods are difficult or unsuitable for this type of generator (*Transactions pages 163–9*).

Welding Transformers. A capacitor discharge by way of a welding transformer is used to supply a closely controlled energy to the welding spot. A number of equations are derived from an analysis of the circuit which allow explicit calculation of the transformer dimensions from the measured components of the impedance (*Transactions pages 154–9*).

Phonograph Reproducers. Of two new phonograph reproducers one is a variable resistance type with a polarized strain sensitive wire resistance generator element and the other is a variable reluctance or magnetic type. Both have low mechanical impedance at stylus tip and high suspension compliance (*Transactions pages 159–62*).

AIEE Nominees. Biographical sketches of the nominees for AIEE 1946–47 national offices are given in the Personals columns (*pages 130–3*).

Correction. The a-c–d-c instrument shown on page 80 of the February issue of *Electrical Engineering* is of the moving-iron type and not of the moving-magnet type as erroneously labelled.

ELECTRICAL ENGINEERING. Published monthly by the American Institute of Electrical Engineers; publication office 20th & Northampton Streets, Easton, Pa. Editorial and advertising offices, 33 West 39th Street, New York 18, N. Y. Subscription $12 per year plus extra postage charge to all countries to which the second-class postage rate does not apply; single copy $1.50. Entered as second-class matter at the Post Office, Easton, Pa., under the Act of Congress of March 3, 1879. Accepted for mailing at special postage rates provided for in Section 538, P. L. & R. Act of February 28, 1925.

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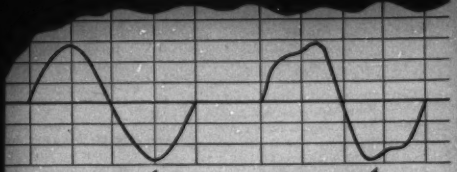

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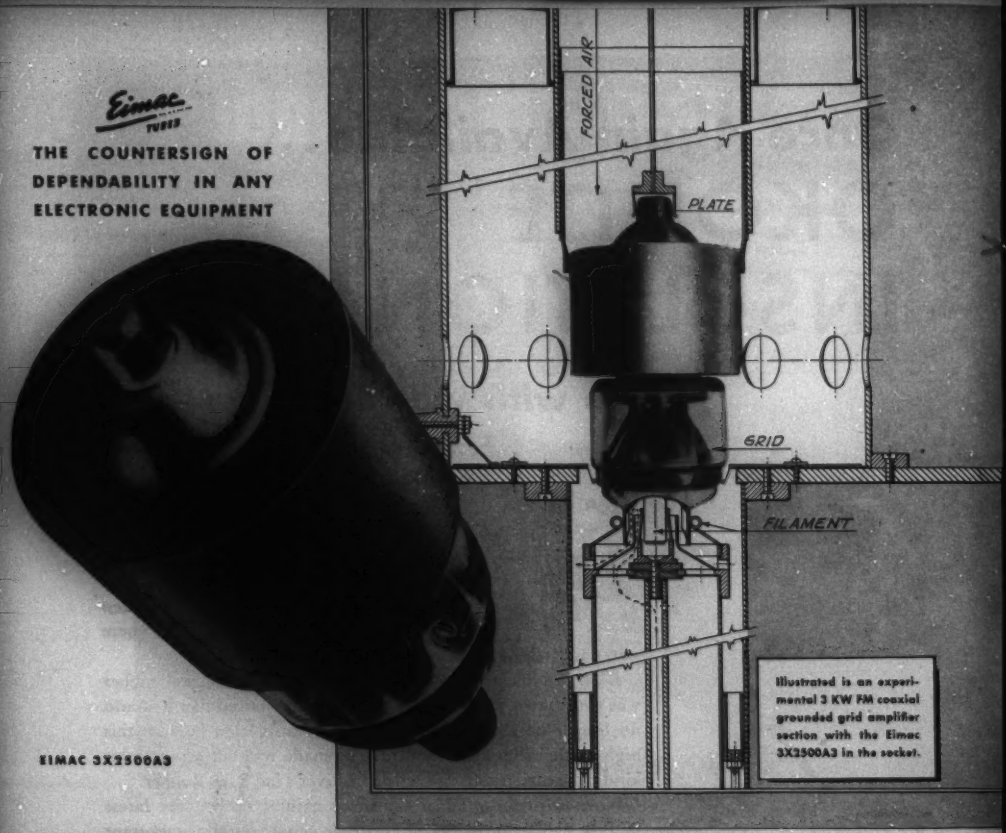

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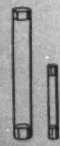

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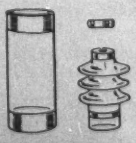

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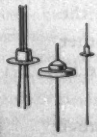

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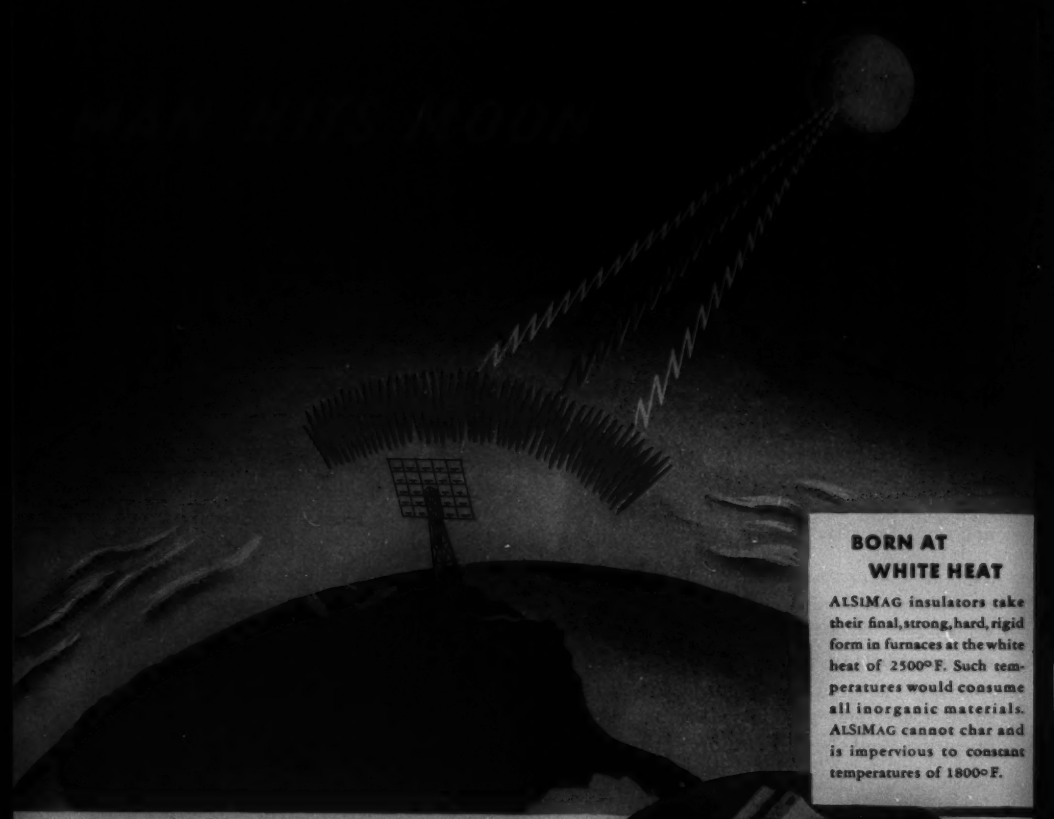

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Communications: Implement to Peace

RAY C. WAKEFIELD

During World War II the United States Army developed a system of world-wide communications unexcelled in scope, both technically and geographically. The author describes some of these improvements and suggests immediate steps to insure the development of a comparable commercial communications system in recognition of the great contribution that instantaneous communication can make to international relations.

IN MODERN TIMES the structure of any industry rests firmly upon its technical development. During the war, the technology of communications underwent revolutionary changes which necessarily affected and will affect further systems of communication, especially international communication.

The first of these developments was the opening up of the higher regions of the spectrum for practical utilization. Before the war, recognized communication services were limited mostly to frequencies under 300,000 kilocycles, although far higher frequencies were known, at least in theory, to be usable. As Federal Communications Commission Chairman Paul A. Porter expressed it in his testimony endorsing the proposed Federal agency for scientific research:

"For many years, the human race has been like a fortunate young wastrel who inherits a vast estate, and then fails to use or even explore more than a portion of it."

That is no longer the case. As a result of wartime research, the upper limit of the usable radio spectrum has been raised to 30 million kilocycles (30,000 megacycles) which makes possible a tremendous expansion of radio services generally.

The so-called "beamed radio relay" is an example of the new services which can be established through the use of these ultrahigh frequency "microwaves." Five companies already have received experimental authorizations from the Federal Communications Commission to construct experimental radio relay beams. In general, their plans involve the erection of a series of low-powered radio stations at intervals of 20 or 30 miles along such routes as New York–Boston, New York–Washington, or even New York–San Francisco. Each of these stations is equipped with highly directional antennas, of a type growing out of wartime radar research, so that it can beam a bundle of radio circuits from point to point without wasting the power of the transmitter in directions other than the direction toward which the circuits are beamed. At each station, a directional receiving antenna picks up the beamed signal, amplifies it, and beams it on to the next relay point making it possible for a large number of telephone, telegraph, teletypewriter, facsimile, and television circuits to be handled simultaneously.

The newly opened regions of the spectrum have short-range characteristics; and while it is possible to overcome this short-range limitation in domestic communications by erecting chains of such stations at intervals across the country, it is not possible to utilize microwaves in this way for transoceanic communication. The region of the spectrum usable for international communications, accordingly, remains limited for the present to frequencies below 30 megacycles but wartime research has brought a number of developments which make possible a much more intensive use of these bands.

One such development is "frequency shift keying" in radiotelegraphy, in which the carrier amplitude remains constant while the frequency is shifted from one value for the "mark" signal to another value for the "space" signal. The two frequencies employed may differ by only a few hundred cycles. This system tends to overcome selective fading as well as certain amounts of interference. Should the signal on either frequency fade or be interfered with, the signal on the remaining frequency can be utilized. Extensive use of this system has been made by the Armed Forces and several commercial companies.

A means of making many signals travel over a channel which formerly carried only one is the awkwardly named "single sideband multitone multiplex transmission" which permits the simultaneous transmission of numerous messages on each side of the carrier, or the transmission of a telephone conversation on one side and several telegraph messages simultaneously on the other. This technique has contributed substantially toward the saving of valuable radio spectrum space.

Still another development is the adaptation of "time division multiplex telegraphy" to radio circuits. Time division multiplex has been in use on wire circuits for a number of years and with modern improvements it has become practicable on radio circuits. This type of multiplex operation, when combined with the use of printers, permits the handling of upward of eight telegraph channels simultaneously by means of a single radio transmitter. This system has contributed more toward the sav-

Essential substance of an address presented before the AIEE San Francisco (Calif.) Section, December 28, 1945.

Ray C. Wakefield is Commissioner, Federal Communications Commission, Washington, D. C.

ing of frequency space than the multitone channeling system, but requires more complicated terminal office equipment than the latter.

Not only have the methods of keying radio transmitters been improved, but keying speeds have been doubled over certain circuits. Whereas 400 words per minute was considered top speed before the war, circuits handling 800 words are now in daily operation. The foregoing techniques are not, of course, necessarily cumulative but rather give alternate methods of improving reliability, speed of service, or otherwise saving frequencies.

Another development, "pulse time modulation," makes use of the fact that the human ear hears a series of rapidly produced sounds as one continuous sound and so, instead of sending out a continuous radio signal, sends out a series of separate pulse-like signals at very frequent intervals. Nevertheless, the transmitter is used for only a fraction of the time to transmit a particular message, and thus the time between pulses is left available for many other messages, similarly pulse modulated. Twenty-four messages have been transmitted simultaneously in this way over a single transmitter.

A somewhat more speculative communication development is "stratovision," a means whereby airplanes, flying in circles at a height of about six miles above the surface of the earth, can be used as relay points. An estimated eight airplanes would be necessary for coast-to-coast relay transmission. Whether stratovision actually will develop such relay systems depends, of course, on relative economic considerations as compared with the relay beam and coaxial cable. One of the most interesting features of this stratovision operation is that the same airplanes which are used as relays also can be used to broadcast to the areas beneath them. One of the problems of frequency modulation and television with their relatively short distances of transmission has been how to reach the rural listeners in the wide open spaces. This broadcasting from airplanes may be an answer to that problem.

Along with these developments, improvements have been made in the facsimile transmission of pictures, printed and written matter, both by wire and radio, and the remarkable development of portable and mobile equipment, including the widely publicized walkie-talkies and handy-talkies.

Technicalities aside, what will these developments mean in terms of ordinary human life? The answer to that question cannot be stated as yet, but it is safe to predict that the tremendous improvements in communications techniques which lie immediately ahead will have at least as great an effect as previous communication developments. Just as the pony express brought California into the commonwealth of states and the transcontinental railroad mail service linked the United States still more firmly as a nation, and just as the coming of the telegraph and the long distance telephone profoundly altered national patterns of thought and action, so it well may be that better communications between countries will strengthen and stimulate mutual understanding and make of us one people of one world.

Technologically, the United States can achieve a world-wide communications system. What are some of the problems, human and otherwise, to be met? Have there been deficiencies in prewar communications operations? If so, how can they be remedied? Perhaps the best way to answer these questions is to compare briefly the status of privately owned communication facilities and the "wartime" world-wide communication system of the Armed Forces.

Privately operated international communication assets, at present, consist of three major communication types. The oldest form of international communication is the cable. The British, who were the great builders of cables during the 19th century, retain a dominant position in the cable picture with control over approximately 58 per cent of the world's cables as compared with the United States which controls, roughly, 32 per cent. The remaining 10 per cent is divided among France, Denmark, and before the war, Italy and Germany. British cables serve some 46 major overseas points while the United States cables link 28 important communication terminals.

Challenging the primacy of the cables is the radiotelegraph, in which field the United States has taken an unchallenged lead with direct linkage to some 70 foreign points of communication as compared with British circuits to approximately 40 overseas points.

Telegraph messages destined for foreign points of communications which are not linked with the United States by direct communication facilities are transmitted to a connecting foreign carrier who then retransmits the message to its point of destination. For example, no direct facilities are available between the United States and Capetown, South Africa, or Rabat, French Morocco, and messages from New York to either place first must be transmitted to London or Paris for retransmission by way of British or French facilities to Capetown or Rabat. The difficulties arising from such roundabout methods of communication are obvious. Details of the operation are duplicated, and there are frequently long hours of delay at the connecting point bottleneck, as such messages become submerged in all of the telegraph traffic of the respective foreign terminal.

A third major means of international communication is the radiotelephone which now provides direct communication between the United States and 39 foreign points of communication which interconnect with the domestic telephone systems of many countries. Eventually it should be possible by means of radiotelephone and landlines to link any two telephones in any two countries of the world.

These three media of communication—the cable, the radiotelegraph, and the radiotelephone—constituted the

communications facilities with which the United States entered World War II. It quickly became apparent, however, that many points of crucial wartime importance could not be reached over these privately owned facilities, and that the combined capacity of such private installations was far from adequate to handle the tremendous volume of international war messages. Accordingly, great systems of communications were established by the Army and Navy under the outstanding leadership of General Frank E. Stoner, Chief of the Army Communications Service of the Signal Corps, and Admiral Joseph R. Redman, Director of Naval Communications. The importance of these military systems of international communications can be indicated by the fact that the estimated investment in the Army and the Navy communications systems totals at least 250 million dollars as compared with private depreciated investments of approximately 54 million dollars in all United States owned international cable, radiotelegraph, and radiotelephone facilities.

Figure 1. Terminal station on a United States Army circuit between Wiesbaden and Augsburg, Germany

The United States Army system is perhaps the only communications system which is world-wide in a literal sense. It radiates from the War Department in Washington, covers the United States by leased landline circuits, and spreads out by radio to every foreign spot where American troops have been stationed. It utilizes the "radio relays" at five strategic locations along the approximate region of the equator. By means of interconnection with teletypewriter devices, it has made the operation of these relay stations semiautomatic, capable of forwarding messages without the delay incident to manual operation. The automatic relay station in receiving the incoming message on a machine perforates a tape which is used to key the transmitter for forwarding the message. Tape perforators and automatic relay stations also have made possible the holding of teletype conferences between parties separated by one-half the circumference of the globe and over circuits which heretofore have been too long and unreliable for this type of service.

Privately owned international radiotelegraph companies maintain direct circuits to such countries as Russia, Australia, New Zealand, India, and China but these circuits cannot guarantee continuous service. To some points they may be usable only a few hours a day because of operating difficulties resulting from the long transmission paths and the proximity of such paths to the north polar regions where they are attenuated severely. The Army's five automatic relay stations located at Algiers, Asmara, New Delhi, Manila, and Honolulu approach the ideal equatorial belt which has been proposed by communication engineers. Its establishment recognized that radio communication in a north–south direction is, generally, more reliable than in an east–west direction, particularly in the northern and southern latitudes and that transmission near the equator is far more reliable than parallel transmission considerably north or south of it. A message to Moscow, for example, instead of being sent by the direct path from San Francisco, and thus being exposed to the absorption encountered in the auroral regions, could be transmitted by wireline to Washington, then by radio to Algiers from where it is relayed automatically to Moscow. This routing avoids the auroral zone and each portion of the route covers a comparatively short distance thus affording communication 24 hours a day.

Expensive and elaborate equipment at both ends of a long direct circuit is required even though little traffic moves over the circuit. The nonavailability of such equipment at low volume traffic points, in many instances, has precluded the establishment of direct circuits between the United States and particular foreign points. The Army relay stations have been used advantageously as a relay point for traffic to and from many of such low volume centers, thus making possible the use of comparatively inexpensive facilities at the foreign end.

As a result of this and other advantages, the international military communications of the United States have indicated how good a world-wide communications system can be. Some military circuits can handle messages at

a rate of 800 words per minute as compared with cable speeds of 40 to 60 words per minute, and private radiotelegraph speeds averaging 60 words per minute. The Army and Navy networks have handled as many as 50 million words per day, compared with a capacity of roughly $12\frac{1}{2}$ million words per day for all the United States private carriers combined. By use of the Army's semiautomatic relay system, it takes a message but $3\frac{1}{2}$ minutes to circle the globe.

If the United States is to have the best possible postwar system of international communications, rather than return to the standards of the prewar period, it seems that certain definite steps must be taken in the immediate future. The following is a brief outline of these steps; not as a matured plan for postwar international communications, but as a bare minimum of what must be done.

First. Strategically located radio relay stations must be established.

In considering this matter, one thing must be borne in mind; namely, that private carriers, and the same would be true of a government in peacetime, will not have the same opportunity that the Army had in setting up its world-wide communications system to place radio transmitters, relay stations, or receivers at almost any place in allied or friendly countries where they were needed or could be used best. The very general practice among nations, to which we rigidly adhere, is that no one but a national citizen, or a corporation of any sovereign nation, or the government itself, can operate communication transmitters upon its territory. This means that despite the fact that semiautomatic relays are not used for original transmissions, diplomatic problems are involved in placing relay stations on foreign territory, and that unlike the Army system which also operated the foreign end of each of its circuits, United States communication carriers must communicate with the foreign agency at the foreign end of each circuit.

The Algiers, Asmara, and New Delhi relay points used by the superlative Army system were made available to the United States for the duration of the war and six months thereafter. Accordingly, their operation cannot be continued in the future under existing arrangements. However, other strategic relay points may be available for American operation. For example, three United States carriers plan to establish radio relays at the International Settlement of Tangier which will serve the same function that the Army–Algiers installation served during the war. Arrangements for one or two additional relay points to close the gap from Tangier to the Philippines and Hawaii might make it possible to continue the world-wide Army relay belt.

Second. Immediate policies are necessary with respect to the disposal of surplus military communications equipment which will insure that the equipment remains continuously useful. Certainly the disposition of the Army relay stations should await immediate diplomatic exploration. There are also other types of communication equipment at present scattered throughout the world. Under the Surplus Property Act, such surplus military communications property cannot be imported into the United States for commercial purposes but either must be junked or used abroad although it is of the utmost importance to world-wide communications that this equipment be kept in working order as part of a postwar communications system.

International communication is, of necessity, a two-way system and a rapid, efficient, and world-wide system of communications depends upon the equipment, practices, and co-operation of the foreign agencies. Inferior equipment at a foreign point can delay and impede communication. The failure of the United States international carriers to establish a more efficient world-wide system has been attributed in no small part to the nonavailability of equipment at the foreign end, or to the inferior equipment in the hands of the foreign carriers with which they communicate. It well may be that one of the most important steps that can be taken to improve international communications is to make any surplus Army and Navy equipment available on the most reasonable terms and conditions possible to foreign agencies.

Finally, and of the utmost importance, it is the author's opinion that the ideal international communications system cannot be achieved without merging into one company all privately owned international telegraph and cable carriers, with the exception of Press Wireless, Inc.

The development of a privately owned international communications system in the United States has been on the basis of bitter competitive struggles among private commercial groups. There are eight international telegraph companies organized for the purpose of handling all classes of traffic. In addition, Press Wireless has built up a world-wide system to major points, originally for the purpose of handling press traffic exclusively, but during the war it was authorized to handle government messages and in some instances commercial traffic. R.C.A. Communications, Inc., and Mackay Radio and Telegraph Company compete in the radiotelegraph field on a world-wide basis. The Commercial Cable Company and Western Union Telegraph Company compete in the Atlantic cable field but link the United States directly to only a few major points of communications in Europe. Commercial Pacific Cable Company, one-fourth American owned, and Globe Wireless operate directly to a relatively few points in the Pacific. Tropical Radio Telegraph Company serves the Caribbean area and Central America and the northern part of South America. The All America Cable and Radio Company and Western Union operate cables to Latin America. Several of these companies (Commercial Cables, All America, Mackay, and the American fourth of Com-

mercial Pacific) are under the common control of the International Telephone and Telegraph Company.

Most of those who work in the international communications field, both in government and in industry, agree that the competition of the United States carriers has forced a wasteful duplication of investment, costs of service, and facilities; that it has required the expenditure of effort and resources of the carriers in their attempts to divert business at major points of communications from one to the other; and that such competitive operations do not lend themselves readily to the routing and distribution of international traffic in the manner most likely to assure prompt and efficient service. Of perhaps even more importance is the fact that competitive carriers make less than full use of the scarce and limited radio frequencies. Despite the rapid improvement in radio art, the supply of radio channels still is limited, and maintaining two circuits along a route where the traffic could be handled by one is clearly wasteful.

The frequency saving argument is an important one. The radio frequencies best suited for long distance communications are so scarce that there is virtual agreement among interested United States Government agencies that no such frequencies will be used for domestic communication where wirelines are or can be made available.

What to do with existing international cables constitutes one of the major postwar communication problems. Radio has forged ahead of cables as a method of communication and has proved itself to be a far less expensive, as well as a more versatile, method of communication. United States radiotelegraph carriers, as stated, have established direct circuits with 70 foreign points as compared with 28 served by direct cable connections; yet the investment, after depreciation, in radiotelegraph is only 10 million dollars as compared with 39 million dollars for cables.

Prior to May 1945, cable and radiotelegraph rates were geared largely to cable costs rather than low cost radio operations. Rates were predicated upon the much higher cable investment costs and distance factors, despite the fact that distance has a very small effect upon the cost of transmitting an international radiotelegraph message. Thus, there arose a pattern of nonuniform rates. Until May 1945 the full rate to London was 20 cents per word, with a press rate of 3 cents a word. Other rates ranged from 29 cents to Finland, to 33 cents to Bulgaria, with a press rate from 4 cents to 9 cents a word, depending upon the United States carriers' route over which the traffic was sent. The full rate to China was 88 cents per word and the press rate varied according to the agreement reached by the United States carrier with the Chinese National Government, ranging from $12\frac{1}{2}$ cents to 16 cents per word.

Since May 1945, for the first time in the history of United States communications, a 20-cent uniform rate, more nearly geared to radio costs, and disregarding distance factors, has been applied to outbound communications from the United States to Europe, Latin America, the Philippine Islands, China, and Asiatic Russia. Press rates to many points of communication also have been reduced. But rates which apply to traffic between the United States and Africa, parts of the Asiatic area, to British Empire points of communication, and to French Empire points of communication remain at their prewar high cable-geared level. For example, the present full rate to Algiers is 30 cents a word; to French Indo-China, 81 cents; to Cairo, 42 cents; and to Australia, 60 cents.

This problem was discussed at a recent conference between United States and British Government and communication representatives in Bermuda and, as a result, it was agreed that, not later than April 1, 1946, rates between any point in the United States and any place in the British Empire will be not more than 30 cents per full rate word and the press rate will be reduced to not more than $6\frac{1}{2}$ cents per word.

Some advocates of merger believe that consolidation should be limited to permitting radio carriers to merge into one company and cable operators in a second company, and that these two companies should fight it out to see which shall survive. The argument advanced in favor of this is that a merged company, embracing both radio and cable, may be weighted with the present depreciated investment in cables of 39 million dollars and so would be held back in its greatest use of radio by its desire to protect its cable investment. Obviously, on an investment cost basis, cables cannot compete effectively with radio, except possibly on the heavy traffic routes.

Against this are the facts that neither the military authorities nor the State Department ever have taken the position officially that cables may not still be required for privacy and secrecy, that it may be desirable to retain cables between points of *high traffic density* for the purpose of saving frequencies, and that some engineers believe that cable operation still may be as economical as radio operation along heavy traffic lanes, such as between New York and London. It is also a fact, however, that many Army and Navy communications authorities have stated that radio operations can be as secret as cables.

The British are much more inclined than we in the United States to attempt to protect the full existing investment in cables. However, that they are not unanimous in this view is shown by the following letter written by Sir Ernest Fiske, formerly a director of the Amalgamated Wireless of Australia, which appeared in the London *Times* on October 16, 1945.

"May I open this letter by stating that I have no personal interest in the economics of any newspaper or press association. I have, however, a keen and long-established interest in the utility and efficiency of British oversea communication services, in which field I have been directly occupied both in pioneering and in operating for many years.

"I have read the published copy of a letter from the president of

the Empire Press Union to the Prime Minister's adviser on public relations concerning the important question of telegraph charges for press messages between the separate parts of the British Commonwealth and Empire, and I am surprised to learn that there should be, in these days, any suggestion of increasing the charges for such communications. I can only imagine one reason to justify any increase in these charges—namely, that the high costs of an older submarine cable service are to be met out of the revenues of more up-to-date beam wireless services. Without such a handicap beam wireless, with its modern improvements, should be capable of linking all British territories for high-speed telegraph communication with great efficiency and at low cost.

"The question whether submarine cables are essential for defense purposes is one to be determined by the expert defense advisers to the Governments, but an alternative question whether a modern system of commercial communication ought to be shackled with a cost required largely for security is one of great concern to the press, to the commerce, and to the social welfare of British people in all parts of the world. No reasonable person would suggest that revenues earned by the British Merchant Marine should be applied to the support of the Navy, nor that the traffic charges of commercial air services should be handicapped by the cost of maintaining a defensive Air Force.

"British territories are located round and about the world in a manner which permits effective use to be made of modern science and engineering to provide efficient radio telegraph and radio telephone services with far greater carrying capacity and much lower operating costs than are possible with long submarine cables. Fuller use of these modern developments, which are largely British in their origin, would involve relatively low capital outlay and would provide such efficient means of communication and such high traffic capacity as to permit of much lower charges being made for all classes of traffic than exist today. In such circumstances there should be no suggestion of increasing the press rate, but rather investigation as to the possibility of substantial reduction for all classes of traffic. The urgent necessity for developing the vast resources of the British nations and colonies all over the world is now widely appreciated, and I submit that a major contributing factor in that development should be the utmost use of scientific and engineering knowledge in the field of cheap and efficient oversea communication."

Sir Ernest's assertion that modern radiotelegraph developments are "largely British in their origin" is subject for debate but his philosophy of international telegraph operations and rate making is agreeable. If cables are to be maintained solely for security purposes, it would seem that the cost should be borne by the taxpayer rather than the rate payer.

It is evident that the same issue of high cable investments versus low radiotelegraph costs, and the same need for cheap world-wide telecommunications, must be faced by the United States. It is the author's opinion that any sensible United States postwar communications program must recognize the increasing obsolescence of existing cable facilities, and that the merged company should take over the existing cables at a price which would be commensurate with their *value* in a merged world-wide communications system. All existing cables may be used as a part of a general communications system so long as the expense of replacement and major repairs does not appear formidable. It is essential, however, that a merged company not be saddled with an investment in cables higher than their worth in a technically

Figure 2. Upper parts of antenna towers of AN/TRC-6 system

advancing industry and that adequate provision be made for amortization following the merger.

There seems to be considerable merit to arguments for the continued existence of Press Wireless, Inc., as an independent press communications agency, provided adequate frequencies can be found, and provided its emergency wartime commercial and governmental traffic services are abandoned. It is not contemplated that the merged carriers shall be prohibited from transmitting press messages, but that the exclusive press carrier should concentrate its operations upon the special needs and requirements of the press for high priority in transmission of press material at low rates throughout the world.

Eventually the merged carrier may supply the press with service so good at rates so low that a separate press carrier will not be necessary but until then the public and the news agencies of the United States are entitled to the continued independent operation of Press Wireless as a carrier of press messages exclusively.

An objection to merger of any kind is the argument that it would abolish competition and that competition is a means whereby benefits are conferred upon the public through better or more efficient goods or services at lower costs. This argument loses much of its weight with reference to public utility operations. Moreover, a merger involving only radiotelegraph and cable carriers retains very real competition. Even if cable and radiotelegraph companies were merged into a single concern, with Press Wireless exempt from the merger,

competition nevertheless would remain among three media of communications; the airmail, the merged radiotelegraph and cable carriers, and radiotelephone. Inferior service or high rates on one type of operation would shift traffic to another. The essence of competition would be retained, while the waste resulting from duplication of identical circuits between identical points would be eliminated. In addition, both the American Telephone and Telegraph Company and Press Wireless have been responsible for many technological communication advances. Exclusion of these companies from the merger would continue to serve as a stimulus to the merged carrier to use the most modern equipment and would provide a yardstick as to whether it was doing so.

These various communication developments have a deeper significance however. At the technological level there seems to be no cause for concern. During the war scientists and engineers outdistanced their prewar achievements and undoubtedly this type of progress will continue unabated. More difficult is the problem of organizing these media of communication upon sound economic and social foundations, so that they will be freely available for the use of the people of the world. And more difficult still will be the ultimate task of assuring that the organized communication facilities of the world will be used in the interests of peace and unity.

No matter what machinery of world organization is evolved, permanent peace cannot come without a more perfect understanding among the peoples and governments of the world, and a world-wide communication system such as has been described can contribute mightily to that understanding. This much of a contribution to world peace is almost certain. Any further contribution depends upon the use that is made of the system.

Centralized Power Generation

PHILIP SPORN
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Central station power, Thomas Edison's outstanding accomplishment, thus far has met the test of economic practicality and commercial success, but its relative economy and dependability in an ever-expanding industrial system presents one of the main problems of the post-war era. Additional problems are posed by the possibilities of atomic energy, although just how great a role it can play in the power generation field probably will not be determined for some time.

THE YEAR 1945 will be notable in history for many things: the year in which the greatest and most widespread war in the history of human civilization came to an end; the year in which the United Nations Organization, with the successful functioning of which so much of the future of civilization is bound up, was launched; and, perhaps above all, the year in which the practicability of atomic fission was established and with it the principle of equivalence of mass and energy demonstrated. That demonstration and the work behind it will affect many phases of existence. But it now begins to look as if, excluding the purely military and the world political fields, it will have its greatest peacetime influence on activities devoted to the generation and transmission of power. It may not be too far amiss to say that whether many of the complex world political problems are solved before the world is subjected to another war, the mere beginning of which would constitute the greatest human tragedy since the beginning of time, will depend in large measure on whether the development of atomic or nuclear energy is diverted from the military field of destruction to the peacetime channels of human betterment. One of the most important of these channels, it appears now, may be the field of centralized power generation.

In that field of power generation Thomas Edison reached his crowning achievement. His genius was responsible for a multitude of inventions that have had a profound influence on modern life: the telephone transmitter, the phonograph, and the kinetoscope. Each of these in turn not only came forth and very soon found broad application, but each continued to spread its influence and to serve as a nucleus about which others could build and develop new ideas, applications, and industries. But none of these, important as they were, had the transcendent effect on life and civilization that Edison's incandescent lamp and his system of genera-

Essential substance of the Edison Medalist's address before a general session of the AIEE winter convention, New York, N. Y., January 23, 1946.

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tion and distribution exercised. True, Edison's initial work did not include transmission; that was to come later with the introduction of alternating current, the development of which, as a matter of fact, Edison unsuccessfully opposed.

But even if Edison was to nod later, that does not detract from the amazing creative genius displayed by him in bringing forth a complete system of central station electrical supply involving the generation of electrical energy on a large scale, its distribution throughout extended areas, and its division into small units radiating in every direction from the point of supply where they could be converted into light, each unit independent of every other and each under the control of the user. Despite the fact that he had no well-established theory to support him, and no precedent to guide him, Edison in the three years between 1879 and 1882, invented, developed, and worked out the principles and details of a comprehensive system of generation, control, distribution, and measurement and did it with a completeness and sureness that is amazing, and that has withstood the test of time.

All this is known perhaps to most of those who have devoted their major efforts to improvements in the field of power supply. What is not known so well is the amount of effort that Edison invested in developing the protective features of his system—fuse blocks, fuses, cutouts, switches, auxiliary busses, special circuit breakers—all of these ideas and inventions literally poured from his brain in a dazzling stream. Truly, Edison was mindful of dependability as an indispensable characteristic of a successful central station system.

Perhaps even less known is Edison's preoccupation with the efficiency of his original system. He had a clear concept that his system not only must meet the requirement of practicability, but also the rigid test of practicality. It had to be an economical system to meet the tough commercial competition of gas. When, in the process of developing his successful dynamo, Edison was confronted with the then generally accepted criterion of sound design, namely, that in order to operate under the best conditions generators must be arranged in such a manner that their internal resistance shall be equal to that of the external circuit, he refuted the idea.

"It is ridiculous," he said. "Do you think I want to lose 50 per cent of the power I apply? Why electric lighting never could be worked commercially on that basis. . . . . I am going to try to make my internal resistance as low as I possibly can."[1] And he did. He was thoroughly alive to the need of having his system economical.

Those who have come after Edison have not followed blindly in his footsteps, but rather have been inspired by his genius and example to continue to explore, invent, and develop new apparatus, devices, and practices to meet the new conditions. As the central station industry grew, there came with that growth new problems brought about by expanding the service area to remote regions and the scope of its use in new applications, undreamed of in Edison's time. Edison's original system, which centered about the Pearl Street station, covered perhaps a single square mile. The coming of a-c transmission extended the limits of this area so that today single areas operating as a co-ordinated unit of 100,000 square miles are not only practicable, but can meet the hard test of economic practicality and commercial success. This has meant that the small community of 2,000 is able to obtain today a supply of electric power of almost unlimited quantity, and of a continuity equal to the highest metropolitan standards.

Alfred Korzybski in his book on man, "Manhood of Humanity," has pointed out that what he considers the true and basic differentiation between the three classes of life, vegetable, animal, and human, is this. The vegetable class is essentially a chemistry-binding group. It combines chemical elements for its existence. That is, it is limited by, and depends for existence entirely on, the chemistry of its immediate surroundings. Animals, on the other hand, are space-binders. They can roam over extensive distances. A lack of food in a particular location need have no adverse effects on individuals or species. Finally, man is differentiated from the other two groups by his time-binding ability. In addition to the chemical-binding and space-binding powers each generation of man is capable of obtaining for itself the results of all ideas, work, and developments of all generations of mankind that have preceded it and, from that base, build and add its share to the substance of human progress.

This philosophic concept is one of the most sapient ideas about man developed in our time. It well could be pondered upon and used as a guiding light by our social scientists, legislators, and statesmen. It is a pertinent fact that, although man since the first dawn of civilization has been a time-binder, his space-binding abilities were not developed fully until the advent of the steam engine which made possible the locomotive and the steamship; the discovery of the principle of electromagnetic induction which produced the telegraph and the telephone; the invention of the internal combustion engine which brought about the automobile and the airplane; and the development of electrical transmission of power. These four, and most definitely the last of them, have made it possible for man to free himself from the fetters of fixed location and have enabled him to carry on almost any activity wherever he so wishes. It is that liberation from the natural source of economical power, whether the stream or the mouth of the coal mine, or from the large center of industrial activity, that has made possible the spreading out of industry to the smaller cities, towns, and villages. This, in turn, has brought with it improvement in the social and economic status of large sections of the population. It is probable that this trend will continue to an even greater extent in the

future than it has been effective in the past. Some have gone so far as to express the thought that it has doomed the further growth of large cities. This does not seem likely. But that it has introduced a balancing or restraining force on the unchecked expansion of large population centers, with its attendant ills, cannot be disputed. This, perhaps, constitutes the major achievement of the central station power art as exemplified in the modern integrated power system serving an extended area or region. But again it cannot be pointed out too strongly that the achievement would have been of no practical significance if it had not been accompanied by two most important characteristics; economy and dependability.

The maintenance of present standards of economy in the generation of electric energy, and then, from there, the advancing of these standards, is going to present a number of problems in the near future even independently of the problem presented by the potentialities of atomic power. The war not only witnessed an unprecedented industrial expansion in the United States, but showed clearly that the curve of that expansion is almost coincident with the curve of expansion of electric energy use. Unquestionably, the former would have been impossible without the latter.

The war also clearly brought into focus a changed viewpoint on fuel resources of the United States, a realization of the importance to the country's future and welfare of the use of its natural gas, petroleum, and higher grade coal resources as chemical compounds, and the assignment of the simple fuel function to the lower qualities of solid fuels. That, in many cases, of necessity will call for greater utilization of transmission if the economic factors are to be kept in balance, and particularly if they are to be improved under the new conditions. Because of that, and because in many cases the economical solution of the transmission problem attendant upon the handling of larger blocks of power calls for voltages higher than any attempted commercially heretofore, a major investigation and research program is being initiated. It will consider those elements of the extra-high voltage transmission problem which are now in the twilight zone of knowledge, but which need to be brought into a fully lighted area if the same reliability, coupled with the same economy, that has been obtained in lower transmission voltages is to continue.

Generation of electric energy, and particularly large scale generation, may be on the threshold of a period that will bring about more profound changes than any hitherto conceived. There has been a great deal of irresponsible talk about atomic energy in the last few months, a good deal of it of the "pie in the sky" variety. On the other hand, not enough people realize the significance of what happened in the New Mexico desert on July 16, 1945, when the validity of the Einstein equation postulating the equivalence of mass and energy was proved dramatically.

True, so far fissionable material has not been used to produce a regulated flow of superheated steam. It is likewise true that a very special boiler will be needed, and no such boiler has been built and probably has not been designed. Nevertheless, the fact that one pound of presently known fissionable materials can release 39×10^6 Btu of heat energy, the equivalent of that available from 1,500 to 2,000 tons of coal, cannot be avoided or neglected. Such elements present an engineering challenge that cannot remain unanswered. Nor is the fact that an atomic energy boiler has not been built up until now a sufficient obstacle. Undoubtedly one can be built. Unquestionably, too, the design of such a boiler will present major problems in heat transfer, in high temperature properties of alloys, and in protection for personnel against harmful radiations. These, however, do not appear to be insurmountable obstacles.

The real problem is one of economics. No one knows, for example, the cost of building such a boiler, nor the cost of operating it, and there is no definite knowledge as to the cost of fissionable materials that can be used in it after it is built. Thus no proper appraisal can be made as to whether such a boiler will bring about more or less economical generation than is possible today through modern steam boilers, and further developments of them, using conventional fuels. It very well may be that, to effect the necessary economy in an atomic power plant, the size of generating units will become far larger than anything previously used in the power field. It is obvious that here again the transmission problem will play an important role. But if atomic power can be developed on an economical and dependable basis, and only one potential plan largely utilizing proved steam equipment has been cited, then it most certainly will find abundant application. If that development should come about it will present but another demonstration of the amazing vitality of Edison's achievement, central station power.

There is no evidence that atomic power forthwith will revolutionize all electric energy supply in the United States, or in any other country having an abundance of economical coal resources. It may, and perhaps will, affect profoundly the generation aspects in some localities. But it will take time, longer than most people realize. The engineering and economic problems are numerous and in peacetime their solution necessarily will take a longer time than is acceptable in wartime. While the challenge that atomic energy presents cannot go unheeded, the extent to which the problems attendant upon its application to the electric power field will be solved completely and the speed with which they are solved will be determined, as they should, by its potential contribution to economical and dependable generation of power.

REFERENCE

1. Menlo Park Reminiscences, Francis Jehl. Part 2.

Progress in Nuclear Research

A review of selected historical highlights of the efforts which culminated in the development of the atomic bomb and its challenge for the future.

BECAUSE its concepts and predictions have been borne out by the results of stimulated wartime research, and because its lucid description of cause and effect of nuclear fission is as good now as a refresher as it was in 1940 as a challenge, the 1940 winter convention address of Doctor Enrico Fermi, of Columbia University and winner of the 1938 Nobel Prize in physics, is here republished.

I. "Nuclear Disintegrations"

Republished from *Electrical Engineering*, February 1940

MUCH OF THE INFORMATION available at present on the structure of atomic nuclei has been gathered by a successful application of the technique of the so-called nuclear bombardments. This technique, initiated about 20 years ago by Lord Rutherford, consists in hurling against the nucleus a projectile (originally this was one of the alpha particles spontaneously emitted by radioactive substances) and in observing the changes in the nuclear structure produced by the impact. In the last years this technique has received new impetus due, on one hand, to the development of artificial sources of high-energy projectiles (high-voltage apparatuses and cyclotrons) and, on the other hand, to the discovery of the neutron.

Several hundreds of different artificial nuclear disintegrations have now been investigated. Their study has led to the development of the so-called nuclear chemistry in which, instead of changes of aggregations of atoms to form different molecules, as in chemistry, changes in the aggregation of neutrons and protons to form different nuclei are observed. This nuclear chemistry obeys rather simple rules, and the different types of nuclear reactions can be summarized as in the following paragraphs.

Nuclei have been bombarded so far mostly with the following types of projectiles: alpha particles, protons, deuterons, and neutrons. Whenever one of these particles strikes the nucleus it is incorporated into the nuclear structure, and another particle may be emitted which belongs to one of the same four types. In a few instances nuclear reactions have been produced by hard gamma rays or by high-energy electrons. We have further to add the many cases of radioactivity, both natural and artificial, in which an unstable nucleus spontaneously emits an alpha particle, or an electron (negative or positive). The residual nucleus that remains after the reaction is always different from the one before the impact. In general, however, the changes in atomic weight, or atomic number, are not very large. Indeed, the greatest changes in atomic number occur when an alpha particle is either absorbed or emitted in the process. Since the electric charge of the alpha particle is of two units, this produces a displacement in the atomic number of two places only.

In many cases in which a chemical identification of the reaction products of nuclear bombardment has been possible, it has been found consistently that the reaction products are either isotopes of the original element bombarded, or they differ from it in atomic number by only a few units. There was, therefore, a great sensation among nuclear physicists last year when Hahn and Strassman announced that by bombardment of uranium (atomic number 92) with neutrons, they had found definite evidence of the formation of some radioactive isotopes of barium (atomic number 56). Such a change by 36 units in the atomic number had never been considered possible before; subsequent investigation has shown that it corresponds to a nuclear reaction of an entirely new kind, in which the uranium nucleus splits into two fragments of comparable size.

This discovery of Hahn and Strassman has opened a very interesting new field of investigation. It is well known that all the heaviest elements of the periodic system are to some extent unstable, as is shown by their natural radioactivity. The physical reason for this instability is the electrostatic repulsion between the positively charged constituents of the nucleus. These repulsions are approximately proportional to the square of the nuclear charge and, therefore, increase considerably with increasing atomic number. Instability sets in when the electrostatic destructive forces overcome what we may call the cohesive forces of the nucleus.

The theory of nuclear forces is not yet developed so far as to enable us to calculate exactly at what value of atomic number instability sets in. Probably, however, this limit is not far beyond 92, the atomic number of uranium. The discovery of Hahn and Strassman shows, indeed, that in the case of uranium the relatively unimportant perturbation of the nuclear structure due to the capture of a neutron is already sometimes sufficient for

breaking into pieces the nucleus, giving rise to the so-called fission process.

A pictorial image of the process has been suggested by Bohr, who compared this process with what happens when a liquid drop divides into two smaller droplets as a consequence of a very strong oscillation in which it changes from the original spherical form into an elongated shape. In the case of uranium, however, as soon as the two fragments are separated and the cohesive forces cease to attract them, the strong repulsion due to both fragments being positively charged, pushes them apart, impressing on them a relatively enormous kinetic energy. In fact, the amount of energy released in the fission process is approximately ten times greater than any amount of energy released in atomic disintegrations, it being of the order of 200 million electron volts. (An electron volt is defined as the amount of energy gained by an electron in passing from a point of low potential to a point one volt higher in potential.) Although the discovery of this process is only one year old, a great many investigations have been carried out in laboratories all over the world, so that a general description of the main features of the phenomenon is now possible, in which, however, many important details are still missing.

The fission process can be produced by bombardment with fast neutrons having energy above one million electron volts, and by slow neutrons, having energy corresponding to thermal agitation equivalent to a small fraction of an electron volt. Neutrons of intermediate energy are rather inefficient as agents for producing fission. It has been pointed out, especially by Bohr, that this fact might possibly be interpreted on the assumption that the fast-neutron and the slow-neutron process are due to two different isotopes of uranium. Probably the fast-neutron process is due to isotope 238, which represents more than 99 per cent of natural uranium, whereas the slow-neutron process might be attributed to a much rarer isotope of weight 235, which is known to be present in an amount somewhat less than 1 per cent and is the parent substance of the actinium radioactive family. No direct experimental information on this point, which is of considerable importance both from the theoretical and the practical point of view, is at present available.

Each fragment into which uranium splits in the fission process weighs approximately one-half of the original nucleus. Apparently, however, the fission does not always occur in exactly the same way, and there are certain limits between which the weight of the fragments can vary. Since each fragment gives rise to several artificially radioactive nuclei, it is clear that the fission process will produce a large variety of new radioactive elements. An extensive chemical investigation of these elements has been carried out in several laboratories and has already led to the identification of more than 20 such elements, but the list is probably still far from being complete.

When uranium undergoes fission some neutrons are emitted. It has not been decided so far whether these neutrons are emitted in the very act of fission, or a very short time after the process. The two fragments into which uranium splits get away with a very high internal excitation. The excitation energy might be so large as to produce the spontaneous emission of neutrons from the two fragments. The largest part of this emission of neutrons certainly occurs within an exceedingly short time after the fission; the emission of a small number of neutrons, however, lasts for some seconds after the fission process. This delayed emission of neutrons is probably a secondary process of some beta disintegration.

The emission of neutrons is not only an interesting feature of the phenomenon, but might perhaps be of far-reaching importance, as it opens at least one possibility of exploiting the fission of uranium for the production of nuclear reactions on a large scale.

Let us assume for a moment that in every fission process two neutrons are emitted (actually experiment shows that probably the average number of neutrons emitted is somewhat larger, between two and three). If this were so every neutron that enters the uranium nucleus and produces fission would give rise to two neutrons with the net gain of one. If we assume that these two neutrons again produce each one a fission we get at the end four neutrons from the original one. Any one of these four neutrons might again produce a fission, multiplying the number of neutrons once more by two, and so forth, until the number of neutrons might in principle be multiplied by an arbitrarily large factor, thus giving rise to a self-perpetuating nuclear reaction—the so-called chain reaction. In order that the chain reaction might occur, it is obviously necessary not only to have more than one neutron produced for every neutron that is absorbed in the process of fission, but also to be able to utilize for producing new fissions a large fraction of the neutrons produced; otherwise the loss might be larger than the gain.

Assuming, as before, that two neutrons are produced in every fission, it is evident that for the chain reaction to take place more than one-half of the neutrons produced must be used in new fission processes. There is now, on one hand, some loss of neutrons that diffuse outside of the reacting mass before they have a chance to react. This loss can be made, at least in principle, arbitrarily small, by increasing the amount of the reacting material. On the other hand, some of the neutrons are lost for the reaction because they are absorbed by uranium itself in a second process, which does not lead to fission but to the formation of a heavy radioactive isotope of uranium. Some absorption is finally due to those substances that must be present in order to slow down the neutrons, so as to increase their aptitude to react with uranium. Whether these absorptions are, or are not, sufficiently large to prevent the chain reaction, cannot be answered at present. The experiments require the use of very large amounts of both uranium and "slowing-down" materials and are, therefore, very expensive. The problem

seems to me, however, worth the effort that its solution will cost. There is indeed a chance that research on these lines might open entirely new technical opportunities, whose range at present only can be guessed. The large release of energy by the reaction, whose development, by the way, could be controlled easily by simple mechanical devices, is indeed probably only one and very likely not the most important aspect of the problem. Far more important might eventually prove the production of radioactive materials and of neutrons in practically unlimited amounts, for medical, biological, and physical investigations. In conclusion, although there is only a chance of success, the stake appears large enough to justify some gambling.

II. Review of Basic Concepts

THE EXTENT to which the foregoing 1940 concepts have been vindicated or exceeded is now a matter of history in the record of the now famous "Manhattan Project" which culminated in the successful development of the so-called atomic bomb. In addition to military implications attention now is turning to the potential industrial uses of nuclear energy. This seems to be an appropriate time, therefore, to review the basic concepts as now understood, especially the more rudimentary ones which usually are taken for granted in a specific technical treatise.

Prior to 1919, no one had succeeded in disrupting the stability of ordinary nuclei or affecting the disintegration rates of those that were radioactive. In that year, Rutherford discovered that high-energy alpha particles could cause change in the nucleus of an ordinary element; specifically, a few atoms of nitrogen were changed into a few atoms of oxygen by bombardment with alpha particles. The process involved may be described as a helium nucleus of mass number 4 (an alpha particle) striking a nitrogen nucleus of mass number 14, producing an oxygen nucleus of mass number 17 and a hydrogen nucleus of mass number 1, the latter known as the proton and of special importance because it has the smallest mass of any nucleus. Continuation of similar experiments led to the discovery in 1940 that when the very energetic alpha particles from polonium fell on such light elements as beryllium, boron, or lithium, "an unusually penetrating radiation" was produced. This radiation was confused at first with gamma rays, but by 1932 was established as the all-important "neutron," an uncharged particle of about the same mass as the proton. Another major discovery was made in 1932: the "deuteron," a nucleus of "heavy" hydrogen (mass 2) which, although not one of the fundamental particles, does play an important role in certain processes for producing nuclear disintegration. Also, "positrons," particles of the same mass as the electron, and of equal but positive instead of negative charge, were discovered to be emitted from nuclei that were artificially radioactive.

Artificial radioactivity was discovered—or accomplished—in 1934. Boron, magnesium, and aluminum, after bombardment by alpha particles, were found to remain radioactive for some time. This result stimulated similar experiments al over the world. In particular, Enrico Fermi of Columbia University reasoned that neutrons, because of their lack of charge, should be effective in penetrating nuclei, especially those of high atomic number such as uranium which strongly repel the charged protons and alpha particles. He was able to confirm his prediction almost immediately, finding that the nucleus of the bombarded atom captured the neutron and thus became an unstable nucleus which then achieved stability by emitting an electron. Thus, the final stable nucleus was one unit higher in mass number and one unit higher in atomic number than the initial target nucleus.

Innumerable experiments since 1934 have led to the production of radioactive isotopes of nearly every element in the periodic table. Altogether, some 500 or more unstable nuclear species have been observed, and in most cases their atomic numbers and mass numbers have been identified. Some revert to stability by the emission of electrons, some by the emission of positrons, some by what is known as K-electron capture, and three by emission of alpha particles. Not only did these artifically radioactive elements play an important role throughout the atomic bomb project, but their future value in medical and other research hardly can be overestimated.

BASIC CONCEPTS

The Conservation of Mass and Energy. The first of the two principles that have been cornerstones of modern science is the 18th century enunciation that *matter* can be neither created nor destroyed, but only altered in form. The second is the 19th century enunciation that *energy* can neither be created nor destroyed, but only altered in form. The first led to the principle known as the law of the conservation of matter; the second is known as the law of the conservation of energy. Up to 1940 these were unaltered and separate. Now, it is known that they are but two phases of a single principle, for it has been discovered that sometimes matter may be converted into energy and energy into matter. Specifically, such a conversion is observed in the phenomenon of nuclear fission of uranium, a process in which atomic nuclei split into fragments with the resulting release of an enormous amount of energy. The development and military use of that energy was the objective of the wartime nuclear research which began in 1940.

The Equivalence of Mass and Energy. The conclusion that the inertial mass of a moving body increases as its speed increases appeared early in the evolution of the theory of relativity. This implied an equivalence be-

tween an increase in energy of motion (kinetic energy) of a body and an increase in its mass. To most practical physicists and engineers, this appeared to be but an interesting mathematical fiction of no particular importance. Even Einstein hardly could have foreseen present applications when, as early as 1905, he stated that mass and energy were equivalent, and suggested that proof might be found through the study of radioactive substances. His conclusion that the amount of energy E equivalent to a mass m was given by the equation $E=mc^2$, where c is the velocity of light, assumes startling proportions when stated in actual numbers in related units. If E is expressed in ergs and m in grams, c must be expressed in the centimeter equivalent of 186,000 miles per second or about one billion feet per second. Thus, it can be shown that a single kilogram (2.2 pounds) of matter if entirely converted into energy would give 25 billion kilowatt-hours of energy! This approximates the total energy generated by the entire United States electric power industry (as of 1939) during a 2-month period at full production. This is a fantastic figure as compared with the 8.5 kilowatt-hours of heat energy—or the 1.58 kilowatt-hours of electric energy—generated from the combustion of an equal amount of coal in the average United States steam-electric generating plant of 1939.

The extreme size of this conversion factor was interesting in several respects. First, it explained why the equivalence of mass and energy never was observed in ordinary chemical combustion. Second, it made clear that no appreciable quantities of matter were being converted into energy in any known terrestrial process, since no such large sources of energy were known. Third, for 25 years it furnished an entirely unsupported basis for vivid speculation, and inspiration for cartoon-strips. By 1930 supporting evidence began to appear in rapidly increasing quantities, and by 1943 had assumed such overwhelming convincing proportions that subsequently even the cartoon-strips were suppressed as a wartime security measure for it was feared that they would be revealing to an alert enemy.

Radioactivity and Atomic Structure. First discovered in 1896, the phenomena of radioactivity have played leading parts in the discovery of the general laws of atomic structure and in the verification of the equivalence of mass and energy. Although the first observed phenomenon of radioactivity was the blackening of photographic plates by the radiations from uranium minerals, the phenomenon of the greatest scientific value is the ability to ionize gases, which quality was discovered shortly thereafter through the observed loss of charge from an electroscope when in the proximity of uranium salts. (The same thing would happen to a storage battery if sufficient radioactive material were placed near it.) Since that time, the rate of discharge of an electroscope has served as a measure of intensity of radioactivity; in fact, nearly all present-day instruments for studying radioactivity depend either directly or indirectly upon this ionization effect.

Studies of absorption and other phenomena have shown that three different types of radiation are given off by radioactive substances:

1. Alpha particles, which are high-speed ionized helium atoms (actually the nuclei of helium atoms).
2. Beta particles, which are high-speed electrons.
3. Gamma rays, which are electromagnetic radiations similar to X rays.

Of these, only gamma rays properly are called radiations, and even they act like particles because of their extremely short wave length. Even though alpha and beta particles are less penetrating than gamma rays, they have enormous kinetic energies for particles of an atomic size, energies thousands of times greater than the kinetic energies which the molecules of a gas have by reason of their thermal motion, and thousands of times greater than the energy changes in chemical reactions. It was for this reason that Einstein suggested that studies of radioactivity might reveal the equivalence of mass and energy, as it has.

The Atom. As presently understood in the light of studies of radioactivity, every atom consists of a small heavy nucleus approximately 10^{-12} centimeter in diameter, surrounded by a largely empty region 10^{-8} centimeter in diameter in which electrons move about somewhat like the planets about the sun. The nucleus carries an integral number of positive charges, each 1.6×10^{-19} coulomb in size. Each electron carries one negative charge of this same size, and the number of electrons circulating around the nucleus is equal to the number of positive charges on the nucleus, so that the atom as a whole has a net charge of zero.

The number of positive charges in the nucleus is called the atomic number, Z, which determines the number of electrons in the extranuclear structure, and this in turn determines the chemical properties of the atom. Thus, all the atoms of a given chemical element have the same atomic number, and conversely all atoms having the same atomic number are atoms of the same element regardless of possible differences in their nuclear structure. The extranuclear electrons in an atom arrange themselves in successive shells according to well-established laws. Optical spectra arise from disturbances in the outer part of this electron structure; X rays arise from disturbances of the electrons close to the nucleus. The chemical properties of an atom depend upon the outermost electrons, and the formation of chemical compounds is accompanied by minor rearrangements of these outer electronic structures. Consequently, when energy is obtained by oxidation, combustion, explosion, or other chemical process, it is obtained at the expense of these structures so that the arrangement of the electrons

in the products of the process must be one of lowered energy content. The atomic nuclei are not affected by any chemical process.

Not only is the positive charge on a nucleus always an integral number of electronic charges, but the mass of the nucleus is always approximately a whole number times a fundamental unit of mass which is almost the mass of a proton, the nucleus of a hydrogen atom. This whole number is called the mass number, A, and always is at least twice as great as the atomic number except in the cases of hydrogen and a rare isotope of helium. Since the mass of a proton is about 1,800 times that of an electron, the mass of the nucleus is very nearly the whole mass of the atom.

Radioactivity and Nuclear Change. If an atom emits an alpha particle (which has an atomic number of 2 and a mass number of 4) it becomes an atom of a different element with an atomic number lower by 2 and a mass number lower by 4. The emission by a nucleus of a beta particle increases the atomic number by one and leaves the mass number unaltered. In some cases these changes are accompanied by the emission of gamma rays. Elements which spontaneously change or "disintegrate" in these ways are unstable and are described as being "radioactive." The only natural elements which exhibit this property of emitting alpha or beta particles are with but minor exceptions those of very high atomic numbers and mass numbers, such as uranium, thorium, radium, and actinium which are the elements known to have the most complicated nuclear structures. All the atoms of a particular radioactive species have the same probability of disintegrating in a given time, so that an appreciable sample of radioactive material, containing many millions of atoms, always changes or disintegrates at the same rate. This rate of change is expressed in terms of the "half-life," which is the time required for half the atoms initially present to disintegrate, a time which evidently is constant for any particular atomic species. Half-lives of radioactive materials range from fractions of a second for the most unstable to billions of years for those which are but slightly unstable. Often the "offspring" nucleus, like the "parent" nucleus, is itself radioactive and so on down the line for successive generations of nuclei until finally a stable one is reached. There are three such families, or series, comprising all together about 40 different radioactive species. The radium series starts from one isotope of uranium, the actinium series starts from another isotope of uranium, and the thorium series starts from thorium. The final product of each series, after 10 or 12 successive emissions of alpha and beta particles, is a stable isotope of lead.

The Neutron. Neutrons are uncharged, a characteristic which distinguishes them from other subatomic particles, delayed their discovery until 1932, makes them very penetrating, makes them impossible to observe directly, and makes them of cardinal importance as agents in nuclear change. Although an atom in its normal state also is uncharged, it is 10,000 times as large as a neutron and consists of a complex "solar" system as previously mentioned of negatively charged electrons widely spaced about a positively charged nucleus. Charged particles (such as protons, electrons, or alpha particles) and electromagnetic radiations (such as gamma rays) lose energy as they pass through matter, and exert electric forces which ionize atoms of the material through which they pass. The neutron is unaffected by such forces; it is affected only by a very short-range force—that is, a force which comes into play when the neutron comes very close to an atomic nucleus. This is the kind of force which holds a nucleus together in spite of the mutual repulsion of the positive charges in it. Consequently a free neutron continues unchecked on its way until it makes a head-on collision with an atomic nucleus. The uncharged nature of the neutron makes it difficult to control as well as to detect. It will not respond to the electric or magnetic fields with which charged particles can be controlled. Furthermore, free neutrons can be obtained only from nuclear disintegrations; there is no natural supply. The only known way of controlling free neutrons is to put nuclei in their way so that they will be slowed, deflected, or absorbed by collisions. These effects are of the greatest practical importance in the atomic bomb project.

Nuclear Structure. The old idea that all elements are made up of but a few fundamental particles now is firmly established; present understanding indicating three: the neutron, the proton, and the electron. Also according to present views, the nuclei of all atomic species are made up of neutrons and protons; the number of protons equal to the atomic number, Z; the number of neutrons (N) being equal to the difference between the mass number and the atomic number, or $A-Z$. Two sets of forces act on these particles; ordinary coulomb forces of repulsion between the positive charges; and very short-range forces of attraction between all the particles, which forces as yet only partly are understood. Suffice it to say that the combined effects of these attractive and repulsive forces are such that only certain combinations of neutrons and protons are stable. If the neutrons and protons are few in number, stability occurs when their numbers are about equal. For larger nuclei, the proportion of neutrons required for stability is greater. Finally, at the end of the periodic table, where the number of protons is more than 90 and the number of neutrons nearly 150, no completely stable nuclei exist, although, as evidenced by their very long half-lives, some of the heavy nuclei are almost stable. When an unstable nucleus is formed artificially by adding an extra neutron or proton, a change to stable form eventually takes place. Strangely enough, this is not

accomplished by ejecting a proton or a neutron, but by ejecting a positron or an electron. In other words, the mass number remains the same, but the atomic number changes. The stability conditions are not very critical, so that for a given mass number (given total number of protons and neutrons) as many as three or five different stable arrangements of protons and neutrons may exist, giving several isobars. For a given atomic number (given number of protons) conditions can vary still more widely, so that some of the heavy elements have as many as 10 or 12 stable isotopes. Some 250 stable nuclei had been identified, ranging in mass number from 1 to 238 and in atomic number from 1 to 92, as of 1940; now, the range has been extended to 239 and 95 respectively.

The theory of nuclear forces still is incomplete, but has been developed on quantum-mechanical principles sufficiently to explain not only the foregoing observations, but also more detailed empirical data on artificial radioactivity and on the differences between nuclei with odd and with even mass numbers.

ENERGY CONSIDERATIONS

That work must be done on a stable system to break it up is a general principle of physics. Thus energy must be supplied to separate into its constituent particles a stable assemblage of protons and neutrons. If energy and mass really are equivalent, the total mass of a stable nucleus should be less than the total mass of the separate protons and neutrons that make it up. This mass difference, then, should be equivalent to the energy required to disrupt the nucleus completely, and is called the "binding energy." Consider the alpha particle as an example. It is stable. As its mass number is 4 and its atomic number is 2, it consists of 2 protons and 2 neutrons. As the mass of a proton is 1.00758 and that of a neutron is 1.00893, the total of the masses of the constituents is 4.03302 whereas the mass of the helium nucleus itself is but 4.00280. Neglecting the last two decimal places, this gives a difference of 0.030 mass unit as representing the "binding energy" of the protons and neutrons in the helium nucleus. This seems like an insignificantly small value, but, by Einstein's equation $E=mc^2$, it figures out to 190,000 kilowatt-hours of energy! Hence, conversely, if free protons and neutrons could be assembled into helium nuclei, this amount of energy would be released. Thus, it evidently was worth while to explore the possibility of getting energy by combining protons and neutrons, or by transmuting one kind of nucleus into another. The first such nuclear change was accomplished in 1932 in an experiment where a target of lithium was bombarded with protons of 700-kv energy and alpha particles ejected from the target as the result of the bombardment. The change resulted in the loss of 0.0185 unit of mass and released energy in the alpha particles of approximately 17 million electron-volts.

This might well lead to the question as to why atomic power plants did not spring up at once in the 1930's. After all, if 2.76×10^{-6} erg could be gotten from an atom of lithium struck by a proton, why should it not be expected that a half-million kilowatt-hours could be gotten by combining a gram of hydrogen with seven grams of lithium?

It looks better than burning coal. The difficulties, of course, lie in the production of the high-speed protons and in controlling the energy produced. The laboratory experiments reported were conducted with infinitesimal quantities of material, fractions of micrograms rather than grams, or pounds. Also, there was the little matter of using up more energy in these experiments in the energizing of the protons than was generated by the nuclear reaction.

III. Chronology of Bomb Research

THE following chronology of selected events especially pertintent to the realization of the alchemists' dream of the centuries is intended to present only a typical cross section of the manifold aspects of the war-stimulated nuclear research. Inevitably, in a brief report on so ramified a project, many important aspects of the famous Manhattan Project and its predecessor and related enterprises are not reported here. Continuing security regulations, too, still prevent discussion of some of the aspects which would be of especial interest to engineers.

1919. Discovery made that high-energy alpha particles could cause an alteration in the nucleus of an ordinary element. Specifically, a few atoms of nitrogen were changed into atoms of oxygen by bombardment with alpha particles. Prior to this no one had succeeded in disturbing the stability of ordinary nuclei or in affecting the rates of disintegration of those that were naturally radioactive.

1930–32. Research in United States, Britain, France, and Germany leads to discovery, identification, and evolution of protons, neutrons, deuterons, and positrons.

1934. Fermi and colleagues first study the results of neutron bombardment of uranium, noting the formation of an unstable nucleus which by subsequent emission of an electron became a stable nucleus one unit higher in mass number and atomic number than the initial target nucleus. Results not properly interpreted until several years later.

January 26, 1939. At a conference on theoretical physics in Washington, D. C., Bohr of Denmark and Fermi of Columbia University discuss possibility of chain reaction related to the currently predicted fission of uranium and resultant release of neutrons. Several

laboratories stimulated into action in effort to confirm or disprove.

February 1939. Fission confirmed by research reports from various laboratories.

March 1939. Fermi reported to Navy Department in conference that achievement of controllable reaction by slow neutrons or explosive reaction by fast neutrons seemed possible, although uncertain on basis of meager information available.

July 1939. Matter finally brought to attention of President Roosevelt by Alexander Sachs of New York, N. Y., acting on behalf of various nuclear scientists, resulting in appointment of Advisory Committee on Uranium, under the chairmanship of Doctor Lyman J. Briggs, director of the Bureau of Standards.

October 21, 1939. First meeting of Advisory Committee on Uranium.

November 1, 1939. First report of uranium advisory committee included recommendation for procurement of 4 tons of graphite and 50 tons of uranium oxide for measurement of neutron-absorption susceptibility or "cross section" of carbon. Also specifically mentioned possibility of both atomic power and an atomic bomb.

February 20, 1940. First transfer of funds ($6,000) from Army and Navy for purchase of materials for the researches recommended by the uranium advisory committee.

February 1940. First small amounts of concentrated fractions of the three uranium isotopes of masses 234, 235, and 238 obtained by use of mass spectrometer. Cyclotron tests soon demonstrated that U-235 was the isotope susceptible to fission by thermal (relatively slow) neutrons.

April 28, 1940. At second meeting of uranium advisory committee, two important new factors were reported:

1. Discovery that the uranium fission caused by neutrons of thermal (low) velocity occurred only in the U-235 isotope.

2. That a large section of Kaiser Wilhelm Institute in Berlin had been set aside for uranium research.

June 1, 1940. By this time, all the following information was generally known, abroad as well as in the United States:

1. That three elements—uranium, thorium, and protoactinium—when bombarded by neutrons sometimes split into approximately equal fragments, and that these fragments were isotopes of elements in the middle of the periodic table, ranging from selenium (atomic number 34) to lanthanum (atomic number 57).

2. That most of these fission fragments were unstable, subject to relatively rapid decay through radioactivity by successive emission of beta particles, thus progressively changing through a series of elements to various relatively stable forms.

3. That these fission fragments had enormous kinetic energy.

4. That fission of thorium and protoactinium was caused only by fast neutrons (velocities of the order of thousands of miles per second).

5. That fission in uranium could be produced by slow (so-called thermal-velocity) neutrons as well as by fast neutrons; specifically, that thermal neutrons caused fission in one isotope, U-235, but not in the other, U-238, and that fast neutrons had a lower probability of causing fission in U-235 than thermal neutrons.

6. That at certain neutron speeds there was a large neutron-capture susceptibility "cross section" in U-238 producing U-239 but not fission.

7. That the energy released per fission of a uranium nucleus was approximately 200 million electron volts.

8. That high-speed neutrons were emitted in the process of fission.

9. That the average number of neutrons released per fission was somewhere between one and three.

10. That high-speed neutrons could lose energy by inelastic collision with uranium nuclei without any nuclear reaction taking place.

11. That most of this information was consistent with the semi-empirical theory of nuclear structure worked out by Bohr and Wheeler and others; this suggested that predictions based on this theory had a fair chance of success.

12. It was realized that capture of neutrons by U-238 probably would lead by two successive beta-ray emissions to the formation of a nucleus of atomic number 94 and mass 239 (later identified and called plutonium).

June 1940. Advisory Committee on Uranium reconstituted as a subcommittee of the newly organized National Defense Research Committee.

November 8, 1940. First NDRC contract for uranium research issued to Columbia University for $40,000.

May 1941. Formation of plutonium ("element 94") reported as result of neutron bombardment of uranium 238.

July 1941. First lattice structure of graphite and uranium set up at Columbia University, an 8-foot graphite cube containing about 7 tons of uranium oxide in iron containers distributed at equal intervals throughout the graphite. Preliminary measurements made in August confirming possibility of controlled chain reaction. Experiments continued with larger structures of similar nature.

July 1, 1941. First Office of Scientific Research and Development research contract calling specifically for study of possibilities of gaseous diffusion method of isotope separation. Work continued through spring of 1945, resulting in huge diffusion separation plants at Oak Ridge, Tenn.

December 1941. By this time 16 uranium research contracts with research organizations had been executed by NDRC, totaling some $300,000. Only few grams of uranium metal and a few pounds of highly impure pyrophoric powder in existence in United States. Metal

cost, $1,000 per pound. Stimulated by British reports of German activity in uranium research, the Office of Scientific Research and Development on December 6 decided upon an unlimited "all-out" effort in the nuclear research program.

Because of the skillful theoretical interpretation of the meager results of the limited research work possible at that time, it could be said that by the end of 1941 the general theory of the chain reaction for slow neutrons was understood almost completely, although numerical constants and technological possibilities still remained uncertain. Appreciable progress also had been made on the theory of a fast neutron reaction in U-235. The proposal had been made that the uranium chain reaction be used for the production of plutonium which was thought to have explosive possibilities appropriate for a "super bomb." Methods of isotope separation had been demonstrated experimentally "in principle" on a laboratory basis with minute quantities and makeshift equipment. This included the mass spectrograph, the centrifuge method, the gaseous diffusion method, the thermal diffusion method, and a debate on the practicality of an electromagnetic method. Although the theoretical understanding was crystallizing rapidly by the end of 1941, very little progress had been made by that time in the production of materials for use in a chain-reacting system. Much progress had been made, however, on analysis. The development of sufficiently accurate methods of chemical analysis of the materials used was a problem of the first magnitude throughout the history of the project, although sometimes overshadowed by the more spectacular problems encountered.

March 9, 1942. OSRD report to President Roosevelt reflected optimism, but stressed tentative nature of conclusions. Suggested that the Army be brought into the project during the summer of 1942 for the construction of full-scale production plants.

June 17, 1942. OSRD report to President indicated conclusively that:

1. A few kilograms of U-235 or plutonium could be detonated with an explosive force equivalent to that of several thousand tons of TNT.

2. Four feasible methods of preparing fissionable material had been developed.

3. Production plants of considerable size could be designed and built.

4. Full-scale plant operation seemed possible soon enough to be of military significance, if supported by adequate funds and priorities.

August 13, 1942. Now famous "Manhattan District" of United States Army Corps of Engineers officially established under innocuous label "Development of Substitute Materials" (DSM), to take over first the procurement and engineering phases of the rapidly expanding project, and later to take over also administration of the various research contracts.

November 5, 1942. Construction of electromagnetic plant at Clinton, Tenn., authorized.

November 1942. Site chosen at Los Alamos, N. Mex., for laboratory to concentrate on design and development of atomic bombs; selection of scientific staff and preparation of construction plans under way for master laboratory.

December 1942. First self-sustaining nuclear chain reaction ever initiated by human beings established December 2. Pile constructed of graphite, uranium oxide, and uranium metal, operated first at 1/2 watt, a few days later at 200 watts. Conclusively proved practicability of controlled chain reaction. Critical size for self-induced chain reaction found to be somewhat smaller than calculated.

Production of raw material improved to extent that uranium metal was available at several hundred pounds per day and cost was down to $22 per pound as compared with $1,000 per pound a year previous.

Total of 500 micrograms of plutonium has been made with cyclotron and separated chemically from uranium and fission products. Enough learned of chemistry of plutonium to indicate possibility of separation on a large scale.

No great advance made in 1942 on bomb theory, but calculations were checked, and experiments with fast neutrons were extended. If anything, the prospects for a successful bomb looked more favorable than a year earlier.

Problems of large-scale separation of uranium isotopes by gaseous diffusion process now well defined by results of research.

January 1943. Plans for pilot plant for development of plutonium production methods well along; to be built at Clinton, Tenn.

Plans for vast plutonium production plant formulated for construction at Hanford, Wash., on a 1,000-square-mile reservation. The magnitude of the project was enormous. Laboratory experiments and calculations had indicated that the production of one gram of plutonium a day corresponded to the generation of somewhere between 500 and 1,500 kw-hr of energy per day. Thus, a plant designed to produce a kilogram of plutonium a day would result in the release and necessary dissipation of 500,000 to 1,500,000 kw-hr of energy per day. The problem, therefore, was to design a plant of this capacity on the basis of laboratory experience with a pile that could operate at a power level of only 0.2 kw. As regards the plutonium separation work, which was equally important, it was necessary to draw plans for an extraction and purification plant which would separate some grams a day of plutonium from some tons

of uranium, and such planning had to be based on information obtained by microchemical studies involving only half a milligram of plutonium. In peacetime, no engineer or scientist in his right mind would consider making such magnification in a single stage, and even in wartime only the possibility of achieving tremendously important results could justify it, and did. A site was chosen on the Columbia River at Hanford, where desert terrain provided plenty of elbow room and the Columbia River provided a cooling medium for the dissipation of huge amounts of energy to be released in the fission process.

Construction of gaseous diffusion separation plant at Clinton, Tenn., authorized. In successful operation by 1945. For the men working on gaseous diffusion it was a long pull from 1940 to 1945, not lightened by such exciting half-way marks as the first chain-reacting pile at Chicago. Perhaps more than any other group in the project, those who have worked on gaseous diffusion deserve credit for courage and persistence as well as scientific and technical ability. For security reasons, it is not possible to tell how they solved their problems—even in many cases found several solutions as insurance against failure in the plant. Work at Columbia University on the separation of isotopes by gaseous diffusion began in 1940, and by the end of 1942 the problems of large-scale separaion of uranium by this method had been well defined. The magnitude of the gaseous diffusion plant can be indicated by its requirement of some 30,000 miles of electrically welded gas-tight seams for gas chambers and ducts; 10 miles of control galleries mounting thousands of instruments.

April 1, 1943. Available information pertinent to design of atomic bomb preliminary and inaccurate. Further and extensive theoretical work on critical size and methods of detonation urgently needed.

April 14, 1943. Assembly of cyclotron started at Los Alamos bomb laboratory; first operation in early July 1943, by 1945 Los Alamos was without question the world's best equipped physics laboratory. At Los Alamos, the research and production results achieved elsewhere were guided and co-ordinated, and the bomb itself was evolved from tenuous theory to demonstrated fact.

May 1943. Correlation of entire project placed under Army control, ending the period of joint OSRD–Army control of the project.

June 7, 1943. Work on assembly of first production piles at Hanford plant begun. Work also under way on plutonium separation plant and a vast array of auxiliary facilities.

November 4, 1943. Clinton pile started, up to 500 kw within a few days; subsequently up to 800 kw and operated at this level until Spring 1944; later operated at more than 1,800 kw.

Clinton electromagnetic separation plant also started this month, and for a year was only production source of uranium 235. It was in large-scale production during the winter of 1944–45, producing U-235 of sufficient purity for use in bombs.

December 20, 1943. First slugs from chain-reacting pile at Clinton pilot plant enter Clinton separation plant; up to one third ton per day by February 1, 1944. The pile itself was simple both in principle and in practice. Not so the plutonium-separation plant. The step from the first chain-reacting pile to the Clinton pile was reasonably predictable; but a much greater and more uncertain step was required in the case of the separation process, for the Clinton separation plant was designed on the basis of experiments using only microgram amounts of plutonium. Nevertheless, the separation process worked!

February 1, 1944. 190 milligrams of plutonium delivered from Clinton separation plant to date; several grams by March 1. Efficiency of recovery, initially about 50 per cent, was above 80 per cent by June.

May 15, 1944. Uranium-and-heavy-water pile ready for test; by July 4, operating at 190 kw; by August 8, operating at 300 kw. Successful, but less susceptible to close control than uranium-and-graphite pile. Hence, plans for production plant cancelled.

Summer 1944. Thermal-diffusion production separation plant hastily built at Clinton, Tenn., to furnish enriched concentrates for processing through the electromagnetic separation plant to enhance its productivity of U-235.

September 1944. First production pile at Hanford plant in operation; second and third piles in operation by early months of 1945. Operation exceeded expectation.

July 16, 1945. World's first atomic bomb exploded in test on New Mexico desert, under scrutiny of Los Alamos laboratory scientists who developed it. Results: devastating, as expected.

August 5, 1945. First military use of atomic bomb; dropped on Hiroshima, Japan, by a B-29 of the 20th Air Force in the Mariannas.

August 10, 1945. Second atomic bomb dropped on a military target, at Nagasaki, Japan, was of different design.

August 14, 1945. Japan capitulates; action obviously precipitated by the atomic bombs, the result of a two-billion-dollar research and production program.

Statistical Methods in Quality Control

X. Classification of Defects and Quality Rating

IN THE CONTINUOUS manufacture of any type of electric apparatus or equipment management often wishes to have the answer to such questions as: How good is the quality of current product? Is it as good as it should be? Is it better or poorer than last week's product? How are we doing compared with six months ago?

To get the answer to some of these questions usually does not require any special data. The data obtained in routine inspections often provide all that is needed. True, in day-to-day inspection work the information obtained in inspection too often is used merely for the purpose of sorting out unsatisfactory product units or for accepting or rejecting individual lots on a sampling basis. But if we make a chain use of these data, tabulating and summarizing them, we readily may get a running picture of quality and the answer to some of the questions which are of importance to those responsible for shop performance.

A simple measure of quality in which the percentage ratio of defective units to total units is calculated usually is adequate for simple products where inspection covers only a few characteristics, but where many characteristics are involved the method is not satisfactory. This article discusses classification of defects according to seriousness and outlines methods of rating quality based upon such classification.

Consider a situation in which we are concerned with the quality of a product of thyratrons being produced more or less regularly at a rate of about 1,200 per week. As for many products, final inspection may consist of testing each unit for mechanical and electrical requirements, gauging critical dimensions, and examining each unit visually for defects in assembly, workmanship, and material. Based on these results, units found to contain defects, that is, failures to meet specified limits or accepted standards of good workmanship, are sorted out and returned to the operating department either for repair, rework, or scrap. This constitutes a 100-per-cent inspection by the method of attributes[1] and provides detailed information which can be used to indicate the quality of the product as it comes from the shop to the final inspector.

One simple measure of such quality would be given by computing the per cent defective, that is, the percentage ratio of defective units to total units. This is often satisfactory for very simple products where inspection covers only a few characteristics, such as screws inspected for dimensions and threading. But where many characteristics are involved, as for most electric apparatus, the value of per cent defective does not provide a very satisfactory yardstick of over-all quality for it fails to take into account that defects of different kinds are not equally serious. Thus for thyratrons an important defect such as an internal cross or ground should have greater weight than an unimportant one such as a slightly cracked base. The method of rating[2] to be considered in the following recognizes such differences in seriousness of defects, and makes use of a system of weighting defects according to their seriousness.

The system can be applied equally well to the results of 100-per-cent inspection whereby the rating reflects the quality of product as it comes from the production line, or to the results obtained from a sample inspection of the finished product whereby the rating may be taken to reflect the quality to the customer.

CLASSIFICATION OF DEFECTS

For present purposes the seriousness of a defect will be judged from the standpoint of the user, taking into account its potential effect on service performance and customer satisfaction. For a given product, a set of defect classes is adopted, each class being defined sufficiently well to assure substantial agreement among different individuals in the process of classifying individual defects. Two classes may be sufficient for some relatively simple products; for others three or four classes may be found desirable.

The principles perhaps can be outlined most readily by considering a simple two-fold classification of defects, designated "major" and "minor." These might be defined, for example, as follows:

Major defects = those that are likely to have a major effect on the operation or life of the unit under normal conditions of use.

Minor defects = those that will have little, if any, effect on operation or life.

A three-fold or four-fold classification would require, of course, a more expansive set of definitions with attention

One of a series of articles prepared in the AIEE subcommittee on educational activities and sponsored by the AIEE subcommittee on statistical methods.

Personnel of the AIEE subcommittee on educational activities: J. Manuele, H. F. Dodge, A. I. Peterson, and R. E. Wareham.

Table I. Calculation of Three Measures of Quality

Week Ending	Number of Units Inspected	Number of Defective Units	Per Cent Defective	Number of Defects Found		Number of Demerits			Demerits-Per-Unit	Index (Standard = 1.9)
				Major	Minor	Major Defects	Minor Defects	Total		
September 1	1,120	39	3.5	17	29	850	290	1,140	1.02	0.54
8	1,310	90	6.9	27	74	1,350	740	2,090	1.60	0.84
15	1,390	111	8.0	80	45	4,000	450	4,450	3.20	1.68
22	1,240	60	4.8	24	44	1,200	440	1,640	1.32	0.69
29	1,460	117	8.0	7	123	350	1,230	1,580	1.08	0.57
October 6	1,510	155	10.3	73	115	3,650	1,150	4,800	3.18	1.67
13	1,130	105	9.3	43	86	2,150	860	3,010	2.66	1.40
20	1,260	100	7.9	34	81	1,700	810	2,510	1.99	1.05
27	1,020	103	10.1	11	104	550	1,040	1,590	1.56	0.82
November 3	1,330	184	13.8	37	190	1,850	1,900	3,750	2.82	1.48
10	1,410	135	9.6	42	121	2,100	1,210	3,310	2.35	1.24
17	1,250	153	12.2	46	140	2,300	1,400	3,700	2.96	1.56
24	910	98	10.8	37	53	2,850	530	3,380	3.71	1.95

perhaps to different degrees of probability of causing trouble with respect to such things as safety, operation, life, maintenance, and appearance.[2]

Having chosen a set of definitions, the next step is to make a list of all kinds of defects, electrical, mechanical, assembly, finish, and so forth, that may be encountered in the inspections under consideration and then classify them individually in accordance with those definitions. A partial defect classification for thyratrons might appear somewhat as follows:

Defect Classification	Class
Cold discharge test: voltage outside specified limits:	
Deviates from limit by more than 20 per cent of limit value	Major
Deviates from limit by 20 per cent or less of limit value	Minor
Bulb contains metal parts	Major
Open filament-support weld	Major
Elements out of alignment:	
Likely to cause failure	Major
Affecting appearance only	Minor
Base cracked	Minor
and so forth	

Here it is noticed that the same type of defect, such as failure to meet limits specified for a particular test, may be given more than one classification according to the degree of departure from the limits.

It remains to choose a suitable set of weights for the two classes. Here only the relative weights are important; the absolute scale of weights is immaterial. The choice is largely empirical and depends in any case on engineering judgment.

QUALITY RATE: DEMERITS-PER-UNIT

Suppose, now, a number of units are inspected in accordance with a definite prescribed procedure. Each observed defect may be weighted by assigning to it a number of demerits, such weight to reflect relative seriousness as contemplated in the classification of defects. All kinds of defects falling in the same class thus are assigned the same number of demerits.

All defects found are counted for rating purposes even though two or more are found on a single unit. The only exception is where one defect is the cause of others. In this case only the most serious one of the mutually dependent defects is counted.

Quality then is expressed in terms of "demerits-per-unit." For the simple case where *all* inspected units are inspected for *all* characteristics under consideration (number inspected, n, is the same for all characteristics), the quality rating in demerits-per-unit is merely the sum of the demerits assessed against defects found, divided by the number of units inspected.

Suppose, for purposes of illustration, we use demerit weights of 50 and 10 respectively for major and minor defects. Let us say that the results of a 100-per-cent inspection of thyratrons over a period of several weeks were as shown in Table I. The method of calculating the rate is indicated in Table I. At the top of Figure 1 is shown a curve of week-by-week values of per cent defective. At the center of Figure 1 is shown the quality rating curve for the demerits-per-unit measure of quality. We note that the demerits-per-unit rating reflects quite a different picture from the per cent defective curve, especially in the third and fifth weeks. In the third week an abnormally high proportion of the observed defects were of major classification, whereas in the fifth week the situation was reversed—the defects were mostly of minor classification.

A little reflection will show that the demerits-per-unit rating is merely a *weighted* measure of degree of nonconformance to requirements. The sum total of specified requirements is used as a convenient standard of reference. With no defects (the best performance attainable relative to this standard), the demerits-per-unit value is zero. Thus, quality performance is measured by a weighted sum of undesirable items, that is, failures to meet requirements.

QUALITY CONTROL CHART

A quality control chart can be constructed for the demerits-per-unit measure of quality in much the same

way as for values of per cent defective. For example, suppose that a standard or expected level of quality based on past experience plus engineering considerations is set at a level of 1.9 demerits-per-unit. This is shown as a dashed line in Figure 1. Three-sigma control limits for this measure may be established from formulas that already have been published[2]:

$$\sigma_{D_u} = \sqrt{\frac{w_1^2(\bar{d}_u)_1 + w_2^2(\bar{d}_u)_2}{n}}$$

and

$$\text{3-sigma control limits} = (D_u)_s \pm 3\sqrt{\frac{w_1^2(\bar{d}_u)_1 + w_2^2(\bar{d}_u)_2}{n}}$$

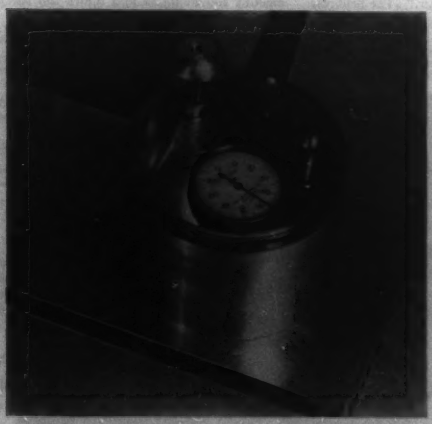
where

σ_{D_u} = standard deviation of demerits-per-unit
$(D_u)_s$ = standard value of demerits-per-unit
w_1, w_2 = demerit weight for major defects and minor defects, respectively
$(\bar{d}_u)_1$, $(\bar{d}_u)_2$ = expected defects-per-unit, for major defects and minor defects, respectively
n = number of units inspected

For the problem cited $(D_u)_s = 1.9$, $w_1 = 50$, $w_2 = 10$, $(\bar{d}_u)_1 = 0.026$, $(\bar{d}_u)_2 = 0.060$, which gives

$$\sigma_{D_u} = \sqrt{\frac{71.0}{n}}$$

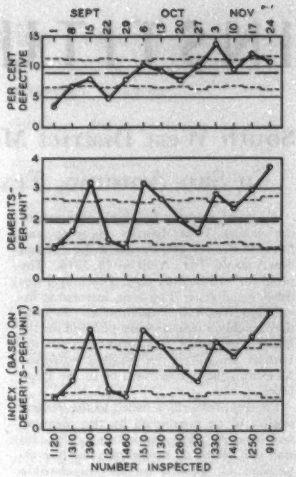
The control limits of such a chart, shown as dotted lines in Figure 1, enable one to see at a glance whether quality at any particular time differs from the standard quality level by an amount that warrants special attention and corrective action.



Glenn L. Martin photo

An instrument gauge of particular value for the inspection of the bonds between the laminar layers of laminated materials as well as for the inspection of single sheets. The gauge operates on the pressure principle

Figure 1. Comparison of three measures of quality



QUALITY RATE EXPRESSED AS AN INDEX

Instead of expressing quality directly in terms of demerits-per-unit, it sometimes may be convenient to express it in the form of an index, namely

$$\text{Index} = \frac{\text{Observed demerits-per-unit}}{\text{Expected demerits-per-unit}}$$

which gives a simple ratio of the observed to the expected number of demerits-per-unit. This gives a form of statistical index similar to that used in other fields, such as for cost of living, coal production, and so forth, in which a current computed value is compared with a standard reference value. The numerical value of the index indicates directly the relation of the observed to the expected degree of nonconformance to requirements, that is, whether it is half, equal to, or twice as great. Such an index is shown pictorially at the bottom of Figure 1. Here the value of "expected demerits-per-unit" is taken to be 1.9, and it will be noted that the curve is identical with that for "demerits-per-unit," except for a simple conversion of scale.

More complex methods of rating over-all quality can be devised, of course, to meet specific situations, but the method outlined here has the advantage of simplicity and can be understood by both supervision and workers.

REFERENCES

1. Statistical Methods in Quality Control II. Two Kinds of Measurement—Variables and Attributes. *Electrical Engineering*, volume 64, July 1945, pages 249–50.

2. A Method of Rating Manufactured Product, **H. F. Dodge.** *Bell System Technical Journal*, volume 7, April 1928, pages 350–8.

INSTITUTE ACTIVITIES

South West District Meeting to Be Held in San Antonio, Tex., April 16-18

A varied program has been arranged for the South West District meeting and Student Branch convention to be held in San Antonio, Tex., April 16–18, 1946. The program will include several technical sessions, some general sessions, interesting inspection trips, and entertainment. In addition luncheon meetings are planned for the District executive committee and for the District committee on Student activities. Meeting headquarters will be in the Plaza Hotel.

Special attention is called to the general session to be conducted by the planning and co-ordination committee. This session will afford an opportunity for free expression of opinion by the membership regarding activities of the Institute. Of especial interest also will be the session on electrical problems in Mexico which now is included entirely in the South West District. This session will be conducted by members from Mexico.

SPORTS AND ENTERTAINMENT

San Antonio has some fine golf courses as well as numerous tennis courts and arrangements will be made for those wishing to play golf or tennis.

On Tuesday evening a stag smoker and supper will be held for which there will be a reasonable charge.

A special feature of the meeting will be the banquet on Wednesday evening to which all, and especially the women, are invited. It will take place at La Villita, picturesque restoration of the early San Antonio settlement, which lies within the shadow of the Plaza Hotel. AIEE President William E. Wickenden will deliver the principal address of the evening. The entertainment will be provided by Mexican dancers and singers. The banquet should prove to be an outstanding event and all are sure to enjoy the novel Mexican atmosphere. Tickets may be secured at the registration desk.

WOMEN'S ENTERTAINMENT

A special committee of women under the leadership of Mrs. N. B. Gussett has been formed to insure an interesting and enjoyable time for the women attending the meeting. The entertainment as planned includes visits to the stores of San Antonio, bridge parties, trips to the famous Missions, to the Alamo, and to the Old Spanish Governor's palace. Further details may be secured upon registration.

RANDOLPH FIELD TRIP

One of the outstanding inspection trips arranged for those attending the meeting is the projected visit to Randolph Field, the "West Point of the Air." The field was closed to visitors during the war and the many changes and improvements which were made will be of great interest even to those who have been there before. Women, also are invited.

Arrangements may be made at the registration desk for trips to any industry or to any of the many historic and scenic attractions in which San Antonio abounds.

HOTEL RESERVATIONS

It is imperative that all members make their hotel reservations early, at least 30 days in advance, by writing directly to the hotel. All the hotels listed in Table I are within a short distance of the Plaza Hotel. If any difficulty is encountered communicate with O. T. Lodal, chairman of the hotels committee.

Table I. Hotel Rates

	Prevailing Rates	
	Single	Double
Plaza, Headquarters Hotel	$2.50–$5.00	$3.50–$7.50
St. Anthony	2.50– 8.00	4.00 up
White-Plaza	2.50– 6.00	3.50– 8.00
Gunter	2.50– 5.00	3.50–12.00
Robert E. Lee	2.00– 3.50	3.50– 6.00
Blue Bonnet	2.00– 3.00	3.50– 6.00

ADVANCE REGISTRATION

Members of the District and others who receive a mailed announcement of the meeting should fill in and return the advance registration card promptly. This will save time at the registration desk and will aid the committee greatly.

The Alamo, famed "Cradle of Texas Liberty," is located in San Antonio, Tex., where the South West District meeting will be held, April 16–18

Tentative Technical Program and Meeting Features

- **PAMPHLET** reproductions of authors' manuscripts of the numbered papers listed in the program may be obtained.
- **ABSTRACTS** of most numbered papers appear on page 130 of this issue.
- **PRICES** and instructions for procuring advance copies of these papers accompany the abstracts. Mail orders are advisable, particularly from out-of-town members, as an adequate supply of each paper at the meeting cannot be assured. Only numbered papers are available in pamphlet form.
- **PAPERS** regularly approved by the technical program committee ultimately will be published in "Transactions"; many will appear in "Electrical Engineering."

Tuesday, April 16

9:00 a.m. Registration

10:00 a.m. General Session

Address of welcome: **Honorable Gus B. Mauermann**, mayor of San Antonio

Presentation of welcome from Mexico

Address: The Institute Today. **H. H. Henline**, AIEE secretary

Address: Tomorrow's Engineering Developments. **M. W. Smith**, vice-president in charge of engineering, Westinghouse Electric Corporation

Address: Engineering Education for Postwar Problems. **A. S. Langsdorf**, dean of engineering and architecture, Washington University

2:00 p.m. Communication

DP.* Some Observations on German Research. **R. S. Glasgow**, Washington University

DP.* Plans and Progress with Radio Relay for a Domestic Telegraph Plant. **F. B. Bramhall**, Western Union Telegraph Company

DP.* Radar for Bombing. **K. E. Gould**, Bell Telephone Laboratories, Inc.

2:00 p.m. Power

DP.* Power Line Carrier for Relaying, Telemetering, Supervisory, and Point-to-Point Communication. **S. C. Leyland**, Westinghouse Electric Corporation

46-83. Operating Experience with Distance Ground Relays. **W. A. Wolfe**, Kansas Gas and Electric Company

46-80. A New Electronic Timing Relay for Reducing Outages on Power Circuits. **F. S. Dioughy**, Oklahoma Gas and Electric Company

DP.* Electrical Power Generation for Water Works Auxiliary Service. **H. F. Lutz**, Black and Veatch, Consulting Engineers

46-82. Some Problems of Distribution Engineering. **R. M. Walker**, El Paso Electric Company

7:00 p.m. Stag Supper and Smoker

Entertainment
Place to be announced later

Wednesday, April 17

9:00 a.m. General Session

Conference on Institute activities, conducted by planning and co-ordination committee

An opportunity for members to participate in a discussion of Institute activities

Final comments. **E. B. Robertson**, past president, Texas Society of Professional Engineers

11:00 a.m. Technical Session

DP.* Some Economic Aspects of the Advance of Industry in the Southwest. **R. A. Mulholland**, consulting engineer

DP.* Supersonic Sharpshooters. **H. H. Hickerson**, Boeing Airplane Company

12:00 noon. Luncheon meeting of Student Branch counselors

2:00 p.m. Inspection trip to Randolph Field

Ladies are included in this trip which will leave the south entrance of the Plaza Hotel. Cars will be provided for those who do not have a means of transportation.

7:00 p.m. Meeting Banquet

Address: **Doctor W. E. Wickenden**, president, AIEE

Entertainment by Mexican singers and dancers

All are invited.

Thursday, April 18

9:00 a.m. Petroleum Industry Applications

DP.* Power Distribution Systems for Oil Field Pumping. **W. C. Bloomquist, J. N. Poore**, General Electric Company

46-81. Modern Diesel-Electric Drilling Rig Equipment. **T. R. Rhea**, General Electric Company

DP.* Magnesium for Cathodic Protection. **J. R. James**, The Dow Chemical Company

9:00 a.m. Selected Topics

DP.* Rural Electrification. **W. B. Bigelow**, Rural Electrification Administration

DP.* New Developments and Improvements in the Design and Manufacture of Electric Equipment. **P. E. Benner**, General Electric Company

DP.* Banking Distribution Transformers; Advantages and Methods. **J. S. Parsons**, Westinghouse Electric Corporation

DP.* An Electronic Moment Indicator. **R. B. Basham**, Consolidated-Vultee Aircraft Corporation

DP.* Power Development in the Freeport-Velasco Area of Texas. **N. D. Grinwald**, Dow Chemical Company

12:00 noon. Luncheon meeting of District executive committee

2:30 p.m. Electrical Problems in Mexico

The following papers have been prepared by several members of the Mexico Section as joint authors. Much of the information contained in them will be of value to the Mexican Government as well as to private concerns in Mexico. They are presented by the Section.

DP.* Electrification Program of the Mexican Republic. Preparation of paper directed by **Basil Nikiforoff**, Mexican Light and Power Company

DP.* Industrialization of Mexico. Preparation of paper directed by **G. David Roldan**, National Economy Bureau

DP.* The Planning of an Electric Equipment Manufacturing Plant in Mexico. Preparation of paper directed by **Eduardo Luque D., Jose Rafael Bejarano**, Industria Electrica

2:30 p.m. Student Session

*DP: District paper; no advance copies are available; not intended for publication in *Transactions*.

No registration fee will be charged for members, Enrolled Students, or immediate families of members. A registration fee of two dollars will be charged of all nonmembers attending.

COMMITTEES

District Meeting:

R. W. Warner, vice-president, South West District; S. R. Friedsam, District secretary; H. P. Heafer; R. C. Horn; E. B. Robertson.

Chairmen of Subcommittees on Arrangements:

N. B. Gussett, general program; A. W. Stariton, meetings and papers; V. H. Braunig, entertainment; O. T. Lodal, hotels and registration; R. J. Foley, transportation and inspection trips; W. F. Helwig, student activities; Mrs. N. B. Gussett, women's entertainment.

Asheville, N. C., Locale of Southern District Meeting

An outstanding technical program is being planned to highlight the Southern District meeting which will be held in Asheville, N. C., on May 14–16, 1946. Meeting headquarters will be the Grove Park Inn, headquarters for the summer convention in 1931. The program will include a symposium on textiles, of special interest to the Southern District because its area contains nearly 75 per cent of all the spindles in the United States.

Two afternoons are being reserved exclusively for recreation and inspection trips. Asheville has a number of attractions for women, including the Biltmore House and Gardens, and the Biltmore Industries, as well as many short scenic trips through the mountains. Five golf courses also are within easy reach. The inspection trips will include the Enka Rayon Plant, the Ecusta Paper Company, manufacturer of cigarette paper, the Aluminum Company's new Glenville hydroelectric plant with 1,150 feet head, and the 80,000-kw Cliffside steam plant of the Duke Power Company which is undergoing a 60,000-kw addition. The board of directors of the Institute will hold its May meeting concurrently with the afternoon meeting on May 14.

Arrangements for the meeting are being made by a committee of the Southern District, of which H. W. Oetinger (M '35) and J. F. Rader (M '40) are cochairmen.

North Eastern District to Meet in Buffalo, N. Y.

Preparations are now in process for a meeting of the North Eastern District to be held in Buffalo, N. Y., April 24–26, 1946, with meeting headquarters in the Hotel Statler. As this will be the first postwar meeting of the District the local committee plans to include many outstanding features on the program.

Nine technical sessions will deal with the following subject matter: power systems, transmission and distribution, electronics, aviation, industrial applications, aviation and transportation, lighting, war developments, and communication, in addition to a conference on quality control. Some of the inspection trips will be correlated so that the equipment described may be seen in operation. Tentatively scheduled for inspection are the Cornell University wind tunnel at the Curtiss-Wright plant, Huntley station, Schoelkopf station, one of the aircraft plants, and Bethlehem Steel Corporation.

Evenings during the meeting will be devoted to entertainment, and as a large number of women are expected to be present arrangements are being made to make their visit an enjoyable one. Among the entertainment features will be a social hour and informal banquet on April 24 and a smoker on April 25. There will be an opportunity for dancing every evening during the meeting.

Arrangements are being made by a committee with T. J. Brosnan (M '34), chairman, and W. S. Hill (M '30), chairman of the local technical program committee.

Schoelkopf station of the Niagara Falls Power Company which is scheduled for inspection during the North Eastern District meeting, April 24–26

Analysis of Verified Registration at Recent Winter Conventions

District	1941*	1943	1944	1945	1946
New York (3)	523	569	608	704	1,123
Middle Eastern (2)	946	417	474	463	645
North Eastern (1)	276	254	301	278	474
Great Lakes (5)	122	97	131	153	200
Southern (4)	27	22	80	40	65
Canada (10)	12	25	29	41	52
South West (7)	2	17	21	32	38
North West (9)	8	6	6	3	7
North Central (6)	12	6	4	1	7
Pacific (8)	3	6	4	3	13
Totals	1,931	1,419	1,658	1,718	2,624

* Previous record registration; Philadelphia, Pa.

Record-Breaking Attendance Distinguishes Winter Convention

Unprecedented attendance marked the first of the AIEE postwar conventions, held in New York, N. Y., January 21–25, 1946. Registration reached the all-time high of 2,624, topping the previous record registration of 1,931 persons at Philadelphia, Pa., in January 1941. A fuller program of social activities also reflected the change from wartime to peacetime.

The aftermath of war was still apparent however, in the convention program. Two sessions on radar, a conference on new industrial uses of electronics resulting from wartime developments, a symposium on nuclear physics, and the addresses delivered at the general session and a joint AIEE-IRE meeting, both of which dealt with atomic energy, were a reminder of the recent conflict.

Of the 14 technical sessions, two were concerned with protective devices, two with instruments and measurements, two with air transportation, and two with electric machinery. Communications, relays, welding, power transmission, and hydroelectric systems also were the subjects of sessions. Others of the nine conferences were held on education, industrial voltage requirements, relays, statistical methods, machine tool and process drives, education, and on the standardization activities of the committee on air transportation. Symposiums on lighting and sound recording completed the technical program for which 78 technical papers and 24 conference papers were prepared and presented. The Transaction section of *Electrical Engineering* beginning with the January issue currently is being devoted to the publication of these papers. Also, many of the special addresses and informal conference presentations will be reflected in early issues of *Electrical Engineering*.

Two medal presentations were made. Presentation of The Edison Medal to Philip Sporn (F '30) vice-president and chief engineer, American Gas and Electric Service Corporation, New York, N. Y., took place at the general session on Wednesday, January 23, at which Doctor J. R. Dunning, director of the division of war research, Columbia University, and technical adviser to the Kellex Corporation, spoke on "Development of Atomic Energy." The jointly awarded Hoover Medal was given to W. H. Harrison (F '31) vice-president of the American Telephone and Telegraph Company, New York, N. Y., at an AIEE–IRE meeting held Wednesday evening. The featured address of that meeting by Major General Leslie R. Groves was "Some Electrical Engineering and General Aspects of the Atomic Bomb Project."

A dinner dance, held at the Hotel Plaza, and the women's luncheon, bridge, and fashion show at the Hotel Pierre, reappeared on the program after a three-year absence. As usual, success of the smoker held on Tuesday was assured before the convention opened, by which time all tickets had been sold. Inspection trips were made to the aircraft carrier *Franklin*, in the Brooklyn Navy Yard, to the Westinghouse Meter Works, Newark, N. J., to Waterside generating station of the Consolidated Edison Company, New York, N. Y., and to the Bell Telephone Laboratories at Murray Hill, N. J.

Many committee and subcommittee meetings and the customary meeting of the AIEE board of directors were held during convention week and are reported elsewhere in this issue.

Personnel of the committees which arranged convention activities follows:

Winter Convention Committee: C. S. Purnell, *Chairman*, J. L. Callahan, M. D. Hooven, R. A. Jones, A. E. Knowlton, J. H. Pilkington, J. J. Pilliod, C. C. Whipple.

Smoker: C. T. Hatcher, *Chairman*, W. J. Barrett, C. F. Bolles, A. J. Cooper, T. C. Duncan, H. E. Farrer,

Analysis of Registration at 1946 Winter Convention

Classification	Dist. 3	Dist. 1	Dist. 2	Dist. 4	Dist. 5	Dist. 6	Dist. 7	Dist. 8	Dist. 9	Dist. 10	Foreign	Totals
Members	838	384	506	53	163	6	32	12	6	40	3	2,043
Men guests	221	66	110	5	31	1	6		1	5	4	450
Women guests	41	20	27	7	6					7		108
Student members	16	4	2					1				25
	1,116	474	645	65	200	7	38	13	7	52	7	2,624

J. B. Harris, Jr., William Jordan, E. B. King, E. G. D. Patterson, D. M. Quick, W. H. Rodgers, H. B. Snow, D. W. Taylor, E. F. Thrall, W. R. Van Steenburgh.

Dinner-Dance: G. J. Lowell, *Chairman*, E. S. Banghart, J. M. Comly, J. G. Derse, E. T. Farish, H. E. Farrer, S. B. Graham, L. F. Hickernell, J. B. MacLean, J. P. Neubauer, Ernst Ohnell, H. C. Otten, E. C. Plant, P. W. Spence, W. H. Taubert.

Inspecton Trips: R. T. Oldfield, *Chairman*, P. H. Adams, E. F. DeTurk, H. E. Farrer, R. W. Gillette, R. K. Honaman, J. R. Kerner, H. H. Nance, W. A. Petrasek, R. M. Pease.

Ladies' Entertainment: Mrs. J. F. Fairman, *Chairman*, Mrs. T. F. Barton, Mrs. R. F. Brower, Mrs. C. W. Franklin, Mrs. R. A. Jones, Mrs. H. S. Osborne, Mrs. J. J. Pilliod, Mrs. C. S. Purnell, Mrs. D. A. Quarles, Mrs. G. S. Rose, Mrs. W. R. Smith, Mrs. G. Sutherland.

Theatre and Broadcast Tickets: H. H. Heins, *Chairman*, G. H. Campbell, G. J. Dyktor, W. Hayden, Jr., H. E. Murphy, T. J. Talley, 3rd.

Boundaries Between Physics and Engineering Discussed at Conference

In opening the conference on education during the winter convention, Professor H. W. Bibber (M '30) chairman of the AIEE committee on education, noted that the employment of physicists and electrical engineering graduates side by side in civilian war research agencies during the past five years had raised pertinent questions as to the boundaries between the work of the professional physicist and the graduate of an electrical engineering curriculum. Some observers, he pointed out, went further, as did an editorial writer in *Fortune* for November 1945 who wrote: "If basic scientists were able to perform important war engineering jobs that were beyond engineers, something is wrong somewhere."

He then stated that the object of the conference was to explore the situation before the important details were forgotten. He expressed the hope that as many facts and as much personal testimony as time permitted might be brought out, and indicated that the question as to what action should be taken in view of what had been revealed by the war would also be in order. He then promised participants anonymity in the reporting of the conference in print, so that no one would feel unduly restrained in the discussion.

Among the well-known physicists and electrical engineers who participated in the discussion were AIEE President W. E. Wickenden (F '39), Doctor L. A. Turner of the Radiation Laboratory at Massachusetts Institute of Technology; Doctor F. B. Jewett (HM '45), and Doctor W. L. Everitt (F '36).

IMPLICATIONS OF ENGINEER'S INFERIORITY DENIED

In summarizing the discussion, it was agreed by all participants that the implied inferiority of the engineer to the physicist did not in fact exist to any appreciable degree, if one compared men of equal intellectual caliber who had received the same number of years of academic training, and whose research experience had been equally broad.

It was suggested that comparisons had been made sometimes between doctors of philosophy in physics with some years of research experience in which they were free to do what they liked, and electrical engineering graduates with only four years of college work whose minds had been routinized by years of industrial experience that was prescribed and restricted, even if it had been called research.

The next point made by several speakers was the fact that the physicist in the war research agencies was using the full range of his talents, whereas the engineer was not able to utilize his cost analysis training, since cost was never a consideration in military devices.

There has never been any question about the contributions of engineers to the design of devices for rapid production. This was as true in the research agencies as in industry. A kind of originality and inventiveness is needed here, but it is not as impressive to the outsider as the original conception of the device. From a practical military standpoint a novel device is of no use unless thousands can be produced quickly.

Certain jobs in war work called for a hybrid type of preparation, in part pure physics and in part engineering. There was some agreement that the physicists were able to pick up the engineering methods that were needed more rapidly than engineers brought into the laboratories from industry could acquire the methods of advanced mathematical analysis and the knowledge of physical theory in fields remote from electrical engineering. The physicists' thinking was not stereotyped and they often came up with unorthodox solutions to problems which led to notable inventions.

In defense of the reputation of the engineers it was pointed out that in setting up the National Defense Research Council and Office of Scientific Research and Development agencies, a great many physicists were put in key positions, and these men called on others in the physics field whom they knew and in whom they had confidence to set up laboratories and assemble staffs. The chain once being started propagated itself. Furthermore, many of the gifted development engineers were in important industrial jobs from which it was inadvisable to move them. Thus, it was asserted, there had been no valid opportunity for comparison, and in any case no direct comparison was possible or significant to engineering education.

Caution in making too many changes in engineering curricula was advised because the physicists' accomplishments in development engineering may have been due to their newness to engineering. If they had continued in engineering work for several

T. G. LeClair (F '40) Commonwealth Edison Company, Chicago, Ill.; S. H. Mortensen (F '20) Allis-Chalmers Manufacturing Company, Milwaukee, Wis.; C. M. Laffoon (M '39) Westinghouse Electric Corporation, East Pittsburgh, Pa.; M. W. Smith (F '42) Westinghouse Electric Corporation, Pittsburgh, Pa. (left to right)

more years their level of accomplishment might have become that of their peers among the professional engineers in industry. Perhaps the broad knowledge which comes from teaching advanced physics in universities and the zest for work which comes from independent research fit the scientists for early successes in engineering development. It may be that their ignorance of the accepted traditions current in the branch of engineering into which they are plunged is an advantage, in that they are not held down initially by any wrong ideas which may have been hallowed into cant by the passage of years. If these things were true then the engineering teachers from colleges who went into the war research agencies may have done as much outstanding work as their physicist coworkers. But the fact seems to be that most mature engineering teachers were asked to stay on in their institutions to teach Army and Navy personnel sent to them, so that little information can be secured on this point.

CRITICAL EXAMINATION OF SCIENCE CONTENT OF ENGINEERING CURRICULA DESIRABLE

Speakers recognized the change that has taken place in the past 40 years in engineering curricula starting from a condition of many hours training in high level skills and coming down to the present with a much lessened content of drawing and shop work, and increased work in fundamental science and associated mathematics. The key question asked was: has each school now the absolute minimum number of hours devoted to these subjects appropriate to the type of engineer they have chosen to educate. It was evident that considerable variety in engineering curricula is desirable, and while a few schools may drop shop work entirely, not all schools would wish to, nor should they do so in the interests of the country.

Application courses took the beating which has been common at engineering education meetings in recent years, along with "informational," "handbook," and "sightseeing" courses. An increase in basic scientific content and more emphasis on possible methods of solving problems rather than the detailed solution of practical type problems were advocated. Fundamental courses in other fields were thought desirable, for example, instead of heat engines and boilers, a course in thermodynamics and heat transfer. Most speakers agreed that industry should provide the application aspect of an engineer's training, not the schools.

Ascribing part of the college problem to the teaching staff, rather than the curriculum, several discussers recalled that the higher salaries in industry had drawn some of the most vigorous and stimulating teachers of engineering graduate subjects and research into industry. Perhaps fewer gifted physicists had been attracted to industry. This intellectual impoverishment of the colleges' engineering faculties is a real problem for industry and the national defense, as the goose that lays the golden eggs, is being killed.

AIEE President W. E. Wickenden (F '39) Case School of Applied Science, Cleveland Ohio, presents the Edison Medal to Philip Sporn (F '30) American Gas and Electric Service Corporation, New York, N. Y. Left to right are J. C. Parker (F '12) Consolidated Edison Company of New York (N. Y.), Inc., eulogist; Mr. Wickenden; Mr. Sporn; and A. E. Knowlton (F '30) *Electrical World*, New York, N. Y., member of the Edison Medal Committee

NEW FRONTIERS IN PUBLICATION OF PAPERS

The new frontiers between electrical engineering and physics in the field of publication of papers were reported to be still fluid, but not confused or undesirably competitive. The field ranged from pure physics at the center, out, as it were, along the spokes of a wheel toward the periphery of engineering application. Before reaching the engineering journals there was a region of emerging technology as differentiated from physics in which a constructive publication service to the engineering fields could be rendered. Particularly if the publications in the applied physics field endeavored to fill gaps not covered by any existing publication, could they render a constructive service.

Philip Sporn Receives Edison Medal

The Edison Medal, highest honor of the AIEE, was awarded for 1945 to Philip Sporn (F '30) executive vice-president, American Gas and Electric Service Corporation, New York, N. Y., "for his contributions to the art of economical and dependable power generation and transmission." The award was made on January 23, 1946, at a general session of the AIEE winter convention, New York, N. Y.

Prior to the presentation A. E. Knowlton (F '30) acting for R. E. Doherty (F '39) chairman of the Edison Medal committee, outlined the history of the medal which was established by a group of friends and associates of Thomas A. Edison to serve "as an honorable incentive to scientists, engineers, and artisans to maintain for their works the high standard of accomplishment" set by Edison himself. Funds for a memorial to the great inventer had been raised from many contributors and, following a period of several years of uncertainty with regard to the best form the memorial should take, the plan of awarding an annual gold medal was adopted in 1908. Since 1909 it has been awarded every year but two by a committee of the AIEE to a resident of the United States or Canada "for meritorious achievement in electrical science, electrical engineering, or the electrical arts."

AIEE Past President John C. Parker (F '12), in an address directed to Mr. Sporn, described the medalist's qualifications for the award. He declared that Mr. Sporn's engineering accomplishments were so many that it would be difficult to select the most meritorious and so it was necessary to substitute an over-all appraisal of Mr. Sporn's work, a principal factor in the development of the power system.

Doctor Parker emphasized the fact, however, that it was not Mr. Sporn's objective achievements that were being signalized by the award but rather his method of approach to problems and their successful solution. "In all your work," he said, "you have shown imagination, systematic logic, and the courage to bring the results of research through the successful processes of design and development into physical being."

In his response after President W. E. Wickenden had presented the medal and certificate, Mr. Sporn reviewed some developments in power transmission and generation, the field in which Edison himself was known best. He remarked that, although it is not known generally, Edison was concerned greatly with the dependability and economy of his power system and that no modern system can have any practical value without these attributes

Edison Medalists

1909	Elihu Thomson	1922	Robert A. Millikan	1934	Willis R. Whitney
1910	Frank J. Sprague	1923	John W. Lieb	1935	Lewis B. Stillwell
1911	George Westinghouse	1924	John W. Howell	1936	Alex Dow
1912	William Stanley	1925	Harris J. Ryan	1937	Gano Dunn
1913	Charles F. Brush	1927	William D. Coolidge	1938	Dugald C. Jackson
1914	Alexander Graham Bell	1928	Frank B. Jewett	1939	Philip Torchio
1916	Nikola Tesla	1929	Charles F. Scott	1940	George A. Campbell
1917	John J. Carty	1930	Frank Conrad	1941	John B. Whitehead
1918	Benjamin G. Lamme	1931	E. W. Rice, Jr.	1942	Edwin H. Armstrong
1919	W. L. R. Emmet	1932	Bancroft Gherardi	1943	Vannevar Bush
1920	Michael I. Pupin	1933	Arthur E. Kennelly	1944	E. F. W. Alexanderson
1921	Cummings C. Chesney			1945	Philip Sporn

a fact which must be considered in our expanding industrial system. This problem, quite independent of that of atomic energy which, Mr. Sporn pointed out, must prove its worth in the electric power field, will be of major interest in the postwar world.

Essentially full text of Mr. Sporn's address appears elsewhere in this issue.

W. H. Harrison Receives Hoover Medal

Continuing the practice of recent years, a joint evening session was held during the AIEE winter convention with the Institute of Radio Engineers which was meeting concurrently in New York. During the first portion of the program, presided over by AIEE President William E. Wickenden, the Hoover Medal was presented to AIEE Past President William Henry Harrison (F '31) executive vice-president in charge of operation and engineering, American Telephone and Telegraph Company, New York, N. Y., and formerly major general, Army of the United States. The second portion of the program, under the chairmanship of IRE President W. L. Everitt (F '36), was devoted to an address, "Some Electrical Engineering and General Aspects of the Atomic Bomb Project," delivered by Major General Leslie R. Groves.

The Hoover Medal is a joint award of the AIEE, the American Society of Civil Engineers, the American Society of Mechanical Engineers, and the American Institute of Mining and Metallurgical Engineers, to "a fellow engineer for distinguished public service." As recalled by Stephen F. Voorhees, ASME representative on the Hoover Medal Board of Award, in his presentation address, General Harrison is the eighth recipient of the medal, the first award being made in 1930 to Herbert Hoover. Mr. Voorhees described the qualifications of the medalist who is being honored, as were his predecessors, not only for his professional services to society, but for other services based upon broad understanding of human needs. He stressed the fact that not only has General Harrison contributed much professionally to the communications industry, but he also has found time to undertake many public services. In recognition of his contributions, General Harrison received the Distinguished Service Medal, the Government's highest award for service off the battlefield.

In his response General Harrison attributed his achievements to the opportunities existent in the United States and to his professional environment. In regard to his wartime experience he paid tribute to those engaged both in combat and industrial duty, predicting that the war-stimulated advances in science and in industry "herald a future so plentiful of goods and of services as to provide for all peoples a better way of life." In his acceptance speech General Harrison confessed that much as he treasured the award his greatest compensation is that satisfaction which a man has when he believes that he has done his duty.

Institute Activities Discussed at Conference

Sponsored by the Institute's committee on planning and co-ordination, a full afternoon conference session during the recent winter convention was devoted to a discussion of Institute activities and relationships with other professional societies. This was the first of several membership forums planned by the committee for the purpose of extending the discussion of these topics, in furtherance of its current special study, as previously reported in *Electrical Engineering*.

President Wickenden, in outlining the necessity and desirability of having such discussion meetings, stated that his "great concern is that the Institute shall be able to respond quickly to fundamental changes in art, science, industry, and the concerns of its members," and be able to "provide such a complete and satisfactory service in these fields that no group will be tempted to step outside the fold and organize separate societies, thus contributing to the progressive fragmentation of the profession." He emphasized also the desirability of "improving the prestige of the engineering profession by having it speak as one voice instead of a babble of 90 voices which very largely cancel each other out to the extent that the engineering profession cannot be influential in public and essentially over-all professional matters."

The first part of the conference was devoted to an informal discussion of the Institute's technical activities sponsored by the technical activities subcommittee. Various suggestions were made for organi-

W. H. Harrison (F '31) American Telephone and Telegraph Company, New York, N. Y. (left) receives the Hoover Medal from S. F. Voorhees, representative of The American Institute of Mechanical Engineers on the Hoover Medal Board of Award. Presentation was made at a joint meeting of the AIEE with the Institute of Radio Engineers during the recent AIEE winter convention

zational or procedural improvements, including a detailed suggestion for decentralization and the establishment of semiautonomous technical divisions the better to foster and correlate technical activities in related subject fields.

The second part of the conference was given over to the discussion of a preliminary report presented by the professional activities subcommittee. This report, reflecting the subcommittee's initial attack on its particular problem, outlined four plans contemplating the more or less complete reorganization of the engineering profession. "Plan A" proposes the consolidation of the various technical and professional organizations in the electrical engineering field into a single electrical engineering organization. "Plan B" proposes continuation of technical activities as at present under the various engineering professional and technical societies, supplemented by a parallel organization which would devote itself to the professional, civic, and other questions of more or less common interest to engineers. "Plan C" proposes the federation of all existing engineering societies, for the correlation of technical activities on the one hand, and the correlation of professional, civic, and other interests on the other hand. "Plan D" proposes the establishment of an entirely new engineering society which would absorb and integrate all activities of all existing engineering and technical societies.

Among the additional topics brought up in the ensuing general discussion were: the professional problems involved in the present industrial trend toward complete unionization, and collective bargaining; the need for a careful study and evaluation of basic aims and objectives. Doctor Funk, AIEE past president and currently acting chairman of the Engineers Joint Council committee on organization of the engineering profession, stated that the work of the professional activities subcommittee and the discussions of the conference session paralleled the work of his committee. Such discussions "can be helpful if the AIEE keeps an open mind, and harmful if the members make any quick decision that some one of the particular plans so far discussed must be adopted. The different national societies have different points of view," he said. In commenting upon the frequently expressed desire to have a society "like the American Medical Association," Doctor Funk pointed out that, quite unlike the engineer, the doctor, regardless of professional specialty practice, always has the same individual and direct doctor-to-patient contact and relationship.

According to the present plans of the committee on planning and co-ordination, the essential substance of the report of its committee on professional activities, together with the essence of the member discussions at the winter convention conference, are scheduled for publication in the April issue of *Electrical Engineering* as a preliminary to further discussion of the matter at the summer convention conference of officers, delegates, and members. April publication will place the matter before the entire membership, and make possible a full discussion of the situation by the various Sections as a basis for orientation of their delegates to the summer convention conference It is expected that the planning and co-ordination committee will be in direct contact with Section officers in the furtherance of such plans for general discussion.

Committees and Subcommittees Meet During Winter Convention

Many AIEE committees and subcommittees held meetings in New York, N. Y., during the week of the 1946 winter convention, in accordance with the usual custom. Matters that are of interest to the membership as obtained from the reports of the committee chairmen are outlined in the following paragraphs.

EDUCATION

Inclusion of certain educational activities as desirable parts of local Section programs was discussed, leading to the establishment of the committee's views that local Sections should seek to stimulate the offering of courses desired by their members in schools and colleges in the Section territory. If such institutions are not available then the local Section should organize them on its own initiative using available meeting space. It was recommended that any AIEE sponsored courses always should carry a substantial fee not only to cover expenses but to stimulate attendance. Educational activity at this time was held particularly appropriate because of the return of veterans and the changes in the work of many engineers. The use of motion-picture films as teaching aids in electrical engineering was considered, and the work of a subcommittee, as done several years ago, was reviewed. It was pointed out that the military services have prepared films for instructional purposes, and that many soon may be made available. Also, manufacturers may contemplate postwar visual education programs, and it is desirable that they should know of the committee's interest in such films. Suggested specific uses for films included animated cartoons for particular devices and films as a substitute for inspection trips, for orientation to show kinds of engineering work, and to indicate professional activities. The possible need of support from educational foundations in producing some films and the need of better arrangements for securing films were discussed.

A new topic discussed was the standardization of laboratory equipment, which was held to offer the possibility of lower prices. The advantages and disadvantages of each school laboratory being a law unto itself were discussed, but in the end it was voted that a subcommittee be appointed to investigate possible standardization.

STUDENT BRANCHES

The most important matter considered at the meeting of the committee on Student Branches was the decision to permit joint Student Branches of AIEE and the Institute of Radio Engineers. It was the recommendation of the committee that the AIEE board of directors be requested to take appropriate action in co-operation with the proper representatives of IRE and to arrange at the earliest opportunity all details essential to the successful operation of the joint branches. Thus Student members in either AIEE or IRE automatically share equal rights in joint Student Branches in addition to the advantages offered by their particular society, and are eligible to transfer to a regular membership grade in either participating society without entrance fee. Hope was expressed that such joint Student Branches eventually will include student members of other societies of similar type and policy.

A decision also was reached to proceed with District student conferences which were interrupted during the war.

MEMBERSHIP

The AIEE membership committee was well represented at the winter convention, members from many Districts being present. The meeting of the committee was enthusiastic with the thought remaining paramount that the committee should continue to be alert to the possibilities of interesting qualified persons in the advantages of Institute membership, and in being helpful to those who desire assistance in filing their applications. There appeared to be no need to change the present policy of the committee at this time.

It is the desire of the membership committee that the present methods of acquainting executives with the aims and activities of the Institute be continued. No change in the procedures being followed in this respect seems to be warranted. The committee has found that its publications for aiding membership activities have been effective and should be continued in their present form. However, another aid in the form of a handy booklet was approved as an additional medium of distributing the information considered pertinent to a person giving thought to applying for membership.

The membership as of January 18, 1946, was 24,309. Approximately 500 applications for membership are posted or are to be posted, and 263 were awaiting final action by the board of directors. Thus, the membership of the Institute is expected to pass 25,000 at an early date—a marked increase since April 30, 1944, when the membership was 21,407. The delinquents are the lowest by a large margin for a great number of years.

Student members totaling 861 have been invited, as is the custom in January of each year, to consider applying for membership in the Associate grade.

TELEMETERING

At a meeting of the AIEE joint subcommittee on telemetering on January 23, the 1941 "AIEE Report on Telemetering, Supervisory Control, and Associated Circuits" was reviewed in preparation for revision. New questionnaires for submission to manufacturers of such equipment were planned, and the co-operation of AIEE members in submitting names and addresses of manufacturers who recently have entered the telemetering field with systems employing electric translating means and suggestions for changes or additions to the earlier report was requested.

It was decided that the 1946 revised report should include at least a brief description of the various physical types of carrier current channels suitable for telemetering and supervisory control, and possibly of the commercially available types of automatic load frequency control, using similar channels, often in combination with telemetering.

LAND TRANSPORTATION

At a meeting of the AIEE committee on land transportation during the winter convention, two subcommittees were appointed, one to revise the Standards for railway control apparatus, ASA C-48, and the other to prepare a questionnaire to be sent to all railroads so that a complete compilation of information on American steam road electrifications and a similar compilation on foreign roads similar to those produced in National Electric Light Association reports of some ten years ago can be made.

Consideration was given to a suggestion that there is a need for standards for electric apparatus used on military vehicles and for other military apparatus.

METALLIC RECTIFIERS

At a meeting of the AIEE subcommittee on metallic rectifiers on January 25, plans were made for the completion of standards on nomenclature including symbols and circuits and of test codes for metallic rectifiers. The subcommittee agreed to meet as a body at least four times during the year, timing the meetings with AIEE District meetings.

INDUSTRIAL CONTROL DEVICES

A new AIEE committee, that on industrial control devices, held a meeting during the winter convention with the objective of determining the place and scope of the committee within the Institute. A subcommittee on electronic industrial control devices has been established to work in coordination with the AIEE committee on electronics, as well as to give full recognition to other organizations which also are working on application of electronics to industrial purposes.

Other plans made by the committee include liaison with the American Society for Testing Materials, which is testing contact materials and shapes, consideration of a bibliography on industrial electrical control, and the desirability of a test code for control devices.

G. A. Burnham (A '03) Allis-Chalmers Manufacturing Company, Boston, Mass.; J. B. MacNeil (F '42) Westinghouse Electric Corporation, East Pittsburgh, Pa.; H. W. Collins (M '42) Detroit Edison Company, Detroit, Mich. (left to right)

PROTECTIVE DEVICES

A meeting of the AIEE subcommittee on fault limiting devices of the committee on protective devices, formerly known as the subcommittee on fault current limiting devices, was held on January 23 under the chairmanship of F. R. Longley (M '42). The name was changed to indicate the full scope of the work of the subcommittee which deals with devices that limit either current or voltage or both under fault conditions.

A new working group was formed to prepare a bibliography concerning system grounding. Progress also was reported on the revision of proposed standards for neutral grounding devices which were prepared for trial use.

The AIEE subject committee on present day grounding practices, which met on January 23, has prepared a questionnaire to be submitted to the principal power companies of the United States and Canada.

POWER GENERATION

At a meeting of the AIEE committee on power generation on January 24, plans were made to sponsor sessions at the forthcoming 1946 summer convention on hydroelectric systems and excitation systems, and at the 1947 winter convention on hydroelectric systems and interconnected electric systems. A long range program has been undertaken by the committee on the subject of hydroelectric systems which in the past has received rather scant attention.

INSTRUMENT TRANSFORMERS

A joint meeting of the subcommittee on instrument transformers of the AIEE committee on instruments and measurements, the test code subcommittee for instrument transformers, ASA transformer Standard C-57, and the AIEE relay subcommittee working group on instrument transformer standards, was held on January 24, primarily to discuss the form of the instrument transformer test code. A proposed form known as the "short form" was accepted.

INSULATION RESISTANCE

At a meeting of the AIEE subcommittee on insulation resistance on January 23, progress was reported on work which is directed toward setting up standards for silicone insulation. It was recommended tentatively that these materials be known as class H insulations and that their maximum hot spot temperature be set at 180 degrees centigrade. The subcommittee also discussed minimum insulation resistance for d-c machines and it is expected that agreement can be reached on proper limits during the coming year.

ELECTROCHEMISTRY AND ELECTROMETALLURGY

At a meeting of the AIEE committee on electrochemistry and electrometallurgy on January 24 there was considerable discussion of the point raised by a number of industrial members of the Institute that AIEE activities and publications do not offer much material of benefit to them. The committee went on record as recommending that an AIEE committee be organized to foster the preparation of papers of the industrial and economic type and that such papers be published in *Electrical Engineering* in a section separated from the highly technical papers which now comprise most of the editorial content.

SAFETY

The committee on safety, L. F. Adams (F '42) chairman, met on January 22. The members were enthusiastic in their support of the program proposed for the committee's activities for the current year. It is expected that the committee will take active steps to assist colleges to improve their engineering courses by inclusion of adequate instruction in the need for and methods of incorporating electrical safety in equipment design and in manufacturing processes.

The committee also expects to continue its present stimulation of interest in active study of electrical hazards, and methods of avoiding or safeguarding against them.

A. W. Hill (M '41) Westinghouse Electric Corporation, East Pittsburgh, Pa.; W. R. Brownlee (M '38) Commonwealth and Southern Corporation, Jackson, Mich.; H. B. Wolf (M '37) Duke Power Company, Charlotte, N. C.; M. H. Hobbs (M '37) Westinghouse Electric Corporation, East Pittsburgh, Pa. (left to right)

Papers on these subjects are contemplated for future meetings.

CARBON BRUSHES

The joint subcommittee on carbon brushes appointed by the AIEE committees on electric machinery and air transportation met to continue preparation of a test code on carbon brushes. The purpose and scope of the code was discussed and preliminary agreement obtained on the outline of contents. Tests under both high altitude and sea level conditions will be included for brushes ranging in size from miniature to those for large machines. Writing of the component parts of the code will begin at once by individuals and groups assigned by Doctor V. P. Hessler (F '43). These will be co-ordinated into a preliminary code. The eventual code will make it possible for manufacturers to publish properties of brushes in accordance with recognized AIEE tests and users will be able to understand the source of published data and to make duplicate tests.

ELECTRONICS

In the absence of the chairman and vice-chairman, W. C. White (M '30) conducted the meeting of the AIEE committee on electronics on January 24.

Doctor C. H. Willis (F '42) presented the "Proposed Standards for Electronic Power Converters" on behalf of his subcommittee. These represented over 2,000 man-hours of work by this group. After some discussion, they were approved subject to certain minor changes outlined by Doctor Willis. They will then be sent to the Standards committee. It was also recommended that they be published as a set of proposed standards.

A report of the electronic power conversion subcommittee on inductive co-ordination aspects of rectifier installations was presented by H. R. Huntley (M '29). This was acted upon similarly.

A report of the subcommittee on nomenclature, definitions, letter and graphical symbols was presented by its chairman, R. S. Burnap (M '29). This covered a considerable number of definitions of various kinds of electron tubes and electronic devices. These, in general, are items not covered by IRE definitions or terms not included by the report of Doctor Willis' subcommittee. With the exception of a certain few definitions on which postponement of action was requested by Mr. Burnap, the report was approved for submission to the Standards committee.

A written or verbal report was made by the majority of the committee's 12 subcommittees.

The chief objective for the present year is an increased activity in promoting interest among Institute members in electronic devices in industry, particularly in certain specialized fields where little has been done by the AIEE.

APPLICATIONS OF ELECTRICITY TO THERAPEUTICS

A meeting of the committee on the applications of electricity to therapeutics was held on January 23. The following problems were discussed:

1. The possible danger to operators who are handling high frequency heating and soldering equipment. It was the general opinion of the committee that workers could be shielded from high frequency fields by interposing a metal barrier between the operator and the source of energy. There was no information as to the amount of heat to which a human may be subjected without injury.

2. The amount of ultraviolet radiation produced by various types of lamps such as sun lamps, sterilizing lamps, and special lamps. The lamp manufacturers expressed their willingness to furnish equipment for a scientific study of the amount of ultraviolet radiation of various wave lengths that are produced by these lamps.

BUSHINGS AND POTHEADS

Culminating discussions and studies that have continued over a period of several years, the subcommittee on bushings and potheads, of the AIEE Standards committee, decided that dielectric test values for potheads should be essentially the same as for apparatus bushings. One school of thought consistently has held out for the use of higher dielectric test values for potheads and for bushings, but field tests and observations carried out over an extended period of time under the surveyance of the subcommittee failed to reveal any justification. Hence, the committee's decision, which is one of far-reaching importance.

SECTIONS

A meeting of the AIEE Sections committee was held on January 22, 1946, with an attendance of 50, at which the results of the conferences on Section operation and management held at the District meetings were discussed. It was the consensus of the meeting that these conferences were very helpful to the Section officers.

The meeting was opened with a short talk by Dr. Wickenden who pointed out that the American Institute of Electrical Engineers is the largest and most rapidly growing of the national societies. He emphasized the importance of meeting the challenge of revolutionary changes in the industry, adding that the local Sections are responding quickly as a result of their being closer to the problems. He then stated that efforts are being directed to make the national organization of the Institute similarly responsive.

Plans were discussed for the delegates meetings to be held at the summer convention in Detroit, Mich. These plans include three conferences on Section operation and management following the pattern used in St. Louis, Missouri, in 1944. These conferences will be entirely informal. The annual meeting of Section delegates will be held after the conferences. The program at this meeting will be devoted strictly to important phases of Section operation and management. Special conferences were also planned to be held later in the summer convention week on the organization and operation of local engineering councils and on student activities.

The development of technical groups was reviewed. The number of such groups in active operation increased from 27 at the end of the 1943–1944 operating year to 51 at the end of the 1944–1945 season, and 23 new groups are reported as having been formed during this year. Many additional groups are being organized as the value of these groups, operated within the Section, is becoming more generally recognized.

The operation of Subsections was discussed as a valuable means of accomplishing the objectives of the Institute by providing additional meeting places at which papers on electrical engineering subjects may be presented and discussed. Six additional Subsections started to function in the present operating year, making a total at present of 21 active Subsections. Six projects for new Subsections were also reported.

The present arrangements for financing the Sections were thoroughly discussed. A plan for increased appropriations is to be presented by the Sections committee for approval.

There was active discussion on the program of the Sections committee for promoting the organization of local councils of engineering and technical societies where they do not exist and encouraging the AIEE Sections to take an active part in the operation of the councils that now exist.

Announcement was made that the Institute pamphlet on prize papers was being rewritten by a special committee. It was the unanimous opinion of those present that any revision of this pamphlet should make adequate provision for Section prize paper contests.

I. M. Stein (F '39) chairman of the AIEE committee on collective bargaining and related matters, reviewed the report of his committee and requested all Section representatives to have individual Section members write to the committee, giving their personal reactions to this report which was published in the July 1945 issue of *Electrical Engineering*.

Conference on Air Transportation

The conference on air transportation sponsored by the AIEE committee on air transportation during the winter convention was held to review the work of the committee on test codes and Standards and to discuss future activities. Following an outline of the procedure followed in the development of Standards and test codes by J. R. North (F '41), the chairmen of active subcommittees presented reports covering their work. It was decided that recommendations would be sought from the aircraft industry and military services for changes in AIEE publication 700, "Preliminary Report on Standard D-C Voltages for Aircraft." This report was issued in March 1945 for a one-year trial period, and action leading to a final Standard is desirable.

A decision was reached to appoint a subcommittee for investigation of safe practices in electric equipment because it was pointed out that electric equipment was blamed for fires and other failures on aircraft, often without any adequate reason. The subcommittee is to make recommendations as to whether the air transportation committee should undertake the problem of making recommendations leading to maximum safety in the use of aircraft electric equipment.

Conference on Statistical Methods

A subcommittee on statistical methods of the AIEE Standards committee sponsored a conference during the winter convention in order to give the membership information about the work which the subcommittee has done during the last year and to aid in planning future activities.

Several speakers emphasized the importance of selling statistical quality control to management. Need was seen for more papers on this phase of the subject at Institute meetings and for interpretive articles to bridge the gap between the theoretical worker and the quality control engineer. Articles of a more advanced type to supplement the educational articles currently appearing in *Electrical Engineering* were advocated.

Informal Conference on Electronics

In keeping with the general theme of "new frontiers" adopted for the winter convention, the electronics committee chose the subject "New Industrial Uses of Electronics Resulting From Wartime Developments" for an informal technical conference.

An analysis of the approximately 250 persons who attended showed the following representation:

Manufacturers of electronic equipment	28 per cent
Other manufacturers	36 per cent
Government laboratories and departments	15 per cent
Educational institutions	10 per cent
Public utilities	8 per cent
Press, consulting engineers and miscellaneous	3 per cent

Practically all the technical advances described resulted from wartime developments in radar. Two speakers described the characteristics or applications of hydrogen-content thyratrons, which have been found suited for operation at frequencies of several thousand cycles per second or where a very high ratio of peak-to-average plate current is required. Their use for pulse testing of windings and generation of frequencies in the audio range was described.

Another speaker discussed magnetrons for the production of frequencies of hundreds or thousands of megacycles per second, pointing out that tubes of this type were suited particularly for sources of power for dielectric heating, because of their good efficiency and circuit simplicity.

Other speakers described recent advances in high-frequency heating and a wide range of new applications. Important features mentioned were automatic tuning of heaters with varying loads, development of specially shaped electrodes for specific applications, and the automatic regulation of output to maintain uniform heating of any one object in a production line even though the number of objects to be heated varied.

It was indicated that much study is being given to heat transfer within the object being heated and that improved knowledge has reduced the amount of application engineering time required on new installations.

Conference on Slow-Acting Relays

A conference under the chairmanship of H. M. Turner (F '44) was arranged by the AIEE communication committee during the winter convention in order to explore the interest in the subject of slow-acting relays as an aid in planning a session on the subject for a future convention.

Slow-acting relays have many uses but their widest application is in automatic telephone systems where they are an essential element. Despite their importance, however, relatively little detailed or even general information is available in the literature. To provide a proper background for general discussion, the following topics were outlined briefly by leaders: Historical aspects, underlying electromagnetic concepts, operational features, and uses of telephone relays for power purposes.

The committee has invited suggestions from all interested members regarding the desirability of holding a session on the subject at the 1947 winter convention, phases of the subject of most interest, and the names of possible authors.

Conference on Machine Tool and Process Drives

A conference on machine tool and process drives was held during the AIEE winter convention under the direction of a newly formed subcommittee with Philip Bliss (A '43) as chairman. The reports submitted by the chairman pointed out that this subcommittee was formed at the beginning of the 1945–46 Institute year for the purpose of developing a report and series of papers covering the modern trend in machine drives, with special emphasis on the newer forms of drives and special controls. One of the major functions of this committee will be to stimulate interest in this subject and bring the user and electrical manufacturer closer together, to their mutual benefit.

Manufacturers frequently are criticized for the design, wiring, and construction practices, especially with regard to maintenance accessibility and operating environment. Machines have been made on which it is practically impossible to perform maintenance and repair work. Frequently the criticism is deserved, but often the user must share the blame for lack of information for specifications. However, closer contact and co-operation between manufacturer and user should prevent much trouble with equipment, unsuitable for the application.

Present methods of installation of motors, control, and accessories in machine tools and other production equipment were criticized as contributing to excessive cost of maintenance. The trend toward enclosing all equipment within compartments to streamline appearance, often results in placing the equipment in inaccessible locations and in locations not satisfactory from an operating standpoint. The automobile industry was reported to have prepared a new standard for the selection and installation of electric equipment which has been placed in the hands of the National Machine Tool Builders Association.

Industrial Voltage Requirements Discussed at Conference Session

Continuing the work begun last year, the AIEE committee on industrial power applications conducted a conference at the winter convention on industrial voltage requirements. As the basis for discussion a preliminary report prepared by the subcommittee on industrial voltage requirements was presented by John Grotzinger

(M '44). The report outlined the effects of voltage variation from various types of electric equipment used in industry and set up permissible system voltage spreads based on a poll of industrial electrical engineers.

In a subsequent discussion of transformer taps and ratios and their bearing on industrial voltage requirements, presented by W. H. Dickinson (M '43) the apparent discrepancy between the voltage zones and the present range of standard taps was pointed out, as was the lack of sufficient information regarding voltage conditions of industrial consumers. It was suggested that a survey be made to determine such voltage conditions to serve as a basis for making an intelligent decision as to what action, if any, should be taken to secure better results from transformers having standard taps and ratios.

R. C. R. Schulze (M '31) discussed some of the difficulties which utilities encounter in trying to provide a power supply that is satisfactory from the standpoints of voltage level and spread. Surveys by industrial engineers and utilities, it was said, should indicate the divergence of voltage conditions from ideal and would permit arriving at the best solution for both.

In discussion it was suggested that AIEE recommendations be permissive rather than mandatory. A proposal was made by H. P. Seelye (F '43) representing the Edison Electric Institute–National Electrical Manufacturers Association group on preferred voltage ratings, that the AIEE industrial power application group co-operate with the EEI–NEMA group before issuing final recommendations. Another discusser expressed the need for co-ordination between designers of lamps and other types of electric equipment because the present ratings of 120 volts for lamps and 440 volts for motors are out of line. Others expressed the belief that terms regarding voltage ratings should be more explicit.

Further consideration of the subject of voltage requirements was proposed for the forthcoming summer convention.

Lamme Medal to D. C. Prince

The award of the AIEE Lamme Medal for 1945 has been made to David Chandler Prince, vice-president of the general engineering and consulting laboratory of the General Electric Company, Schenectady, N. Y., and past president of AIEE "for his distinguished work in the development of high voltage switching equipment and electronic converters."

The AIEE Lamme Medal, which is an annual award to an engineer "who has shown meritorious achievement in the development of electrical apparatus or machinery," was established through a bequest of the late Benjamin G. Lamme, chief engineer of the Westinghouse Electric Corporation. Disposal of the Medal is decided by an AIEE committee organized for that purpose. The first award was made in 1928. A biographical sketch of Doctor Prince appears on page 130 of this issue.

Future AIEE Meetings

South West District Meeting
San Antonio, Tex., April 16–18, 1946

North Eastern District Meeting
Buffalo, N. Y., April 24–26, 1946

Southern District Meeting
Asheville, N. C., May 14–16, 1946

Summer Convention
Detroit, Mich., June 24–28, 1946

Pacific Coast Convention
Seattle, Wash., in week of August 26–30, 1946

Great Lakes District Meeting
Fort Wayne, Ind., September 25–27, 1946

SECTION • • • • •

Toronto Section Forms Communications Group

As the culmination of many suggestions made by members of the AIEE Toronto Section, a communications technical group was formed by that Section late in the autumn of 1945. The formation of such an organization provides an opportunity for the presentation of communication papers and their discussion in technical detail.

The first meeting of the new group was held in the University of Toronto, Ontario, Canada, January 18, 1946, at which L. C. Ratcliffe (A '44) toll and transmission engineer, plant engineering division, Bell Telephone Company of Canada, presented a paper entitled "A 12-Channel Carrier Telephone System for Toll Cables." About 75 persons attended of whom 22 were members. Nineteen of the 53 nonmembers present requested application forms for membership in the Institute.

ABSTRACTS • • • •

TECHNICAL PAPERS previewed in this section will be presented at the AIEE South West District meeting, San Antonio, Tex., April 16–18, 1946, and will be distributed in advance pamphlet form as soon as they become available. Copies may be obtained by mail from the AIEE order department, 33 West 39th Street, New York 18, N. Y., at prices indicated with the abstract; or at five cents less per copy if purchased at the meeting registration desk.

Mail orders will be filled AS PAMPHLETS BECOME AVAILABLE

Industrial Power Applications

46-81—Modern Diesel-Electric Drilling Rig Equipment; *T. R. Rhea (A '41). 25 cents.* A modern Diesel-electric powered drilling equipment for drilling oil wells consists of several internal combustion engines driving d-c generators which supply adjustable voltage power to the several d-c motors driving the various motions. This paper gives: a description of the functions performed by the draw works, mud pumps, rotary table, and coring reel; a typical arrangement of apparatus or elementary power diagram showing the main d-c circuits with the arrangement of drill hoist contactors and manual transfer switches; the general scheme of operation, strictly from the driller's point of view, without the details of how these functions are accomplished; the operating principles of the electrohydraulic governor that make this scheme of operation possible as well as the various control features provided by the amplidyne excitation of the main generators.

Protective Devices

46-80—A New Electronic Timing Relay for Reducing Outages on Power Circuits; *F. S. Dlouhy (A '39). 15 cents.* This paper describes a new timing relay for controlling relaying time on automatically reclosed circuit breakers on which inverse-time overcurrent relays are supplemented by instantaneous overcurrent relays. This device incorporates the advantages of instantaneous circuit breaker opening on the first, and in some cases the second, tripout to clear transient faults, and inverse-time opening on subsequent tripouts to obtain co-ordination with branch or sectionalizing fuses. It was designed for universal application on feeder circuits of the Oklahoma Gas and Electric Company system. And it was designed with certain features which provide for optimum service reliability.

46-83—Operating Experience with Distance Ground Relays; *W. A. Wolfe (M '36). 20 cents.* The theory of distance ground relaying has been known since 1931, and distance ground relays have been commercially available since about 1936, but they have not been very generally used. In this paper a brief résumé of the theory of distance ground measurement is presented, and the advantages and disadvantages of such relays are outlined. Operating experience involving 10 installations of distance ground relays on a 60-kv transmission system is given. The first installation was completed in 1938 and the latest in 1943.

PERSONAL • • • •

David Chandler Prince (A '16, F '26) vice-president, general engineering and consulting laboratory, General Electric Company, Schenectady, N. Y., has been awarded the AIEE Lamme Medal for 1945 "for his distinguished work in the development of high voltage switching equipment and electronic converters." Born February 5, 1891, in Springfield, Ill., Doctor Prince was graduated from the University of Illinois in 1912 with the degree of bachelor of science in electrical engineering and received the degree of master of

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D. C. Prince

W. I. Slichter

J. E. Housley

science in 1913. After a brief interval in the test department of the General Electric Company, he became assistant to the electrical engineer of the Public Utilities Commission of Illinois in 1914, in which position he remained until he was commissioned first lieutenant in the United States Army in 1917. At the end of the war he returned to the General Electric Company and was attached to the radio department until in 1923 he entered the research laboratory. In 1931 he was transferred to the company's Philadelphia works as chief engineer of the switchgear department. He went back to Schenectady as manager of commercial engineering in 1940 and in 1941 was made vice-president of application engineering. He was appointed vice-president of the general engineering and consulting laboratory in 1945. Doctor Prince was president of AIEE for 1941–42 and a director for 1938–41. He has served on many AIEE committees including protective devices, Lamme Medal, board of examiners, finance, Edison Medal, Charles LeGeyt Fortescue Fellowship, transfers, air transportation, planning and co-ordination, and the joint committee on postwar planning, and has represented the Institute on the John Fritz Medal Board of Award and the Charles A. Coffin Fellowship and Research Fund Committee. Doctor Prince was chairman of the AIEE Philadelphia Section for 1940–41. He holds the honorary degree of doctor of science from Union College, is the author of technical papers, and has had many United States patents issued in his name. He was selected as a modern pioneer of industry in 1940. Doctor Prince also is a member of the American Society of Mechanical Engineers, the Institute of Aeronautical Sciences, the Society of Automotive Engineers, and the Institute of Radio Engineers. Recently he has been occupied in postwar planning activities for the Committee for Economic Development as well as for the General Electric Company.

J. E. Housley Nominated for AIEE President

J. Elmer Housley (A '19, M '39, F '43) district power manager, Aluminum Company of America, Alcoa, Tenn., has been nominated to serve as president of the AIEE for the 1946–47 term. Mr. Housley was born in Knoxville, Tenn., January 9, 1893, and was graduated from the University of Tennessee with the degree of bachelor of science in electrical engineering in 1915. He joined the Aluminum Ore Company, East St. Louis, Ill., in 1915 and in 1922 joined the Aluminum Company of America's sales organization, serving as sales engineer in the Kansas City (Mo.) office until 1923. In the latter year he returned to the Aluminum Ore Company and for a year was engaged in special engineering work. In 1924 he became assistant district electrical superintendent for the Aluminum Company of America, Alcoa, and in 1927 he was made superintendent of power, a position he held until 1943, at which time he was named district power manager. Mr. Housley has been an active member of the Institute. He was vice-president for the Southern District (4), 1941–43; chairman, Tennessee Section 1938–39, and is serving on many committees including technical program, 1944–47; Standards, 1944–47; and electrochemistry and electrometallurgy, 1939–47; chairman, 1944–46. He has contributed a number of articles to the technical press and various engineering societies. Other details on Mr. Housley's career were given in *Electrical Engineering*, November 1944, page 413.

W. I. Slichter Renominated for Office of AIEE Treasurer

Walter Irvine Slichter (A '00, M '03, F '12) professor emeritus of electrical engineering, Columbia University, New York, N. Y., has been renominated AIEE treasurer, an office he has held since 1930. A native of St. Paul, Minn., Mr. Slichter was graduated from Columbia University with the degree of electrical engineer in 1896. After an association of seven years with the General Electric Company, Schenectady, N. Y., he was appointed professor and head of the department of electrical engineering at Columbia University in 1910 and has been professor emeritus since 1941. Mr. Slichter has been very active in Institute affairs. He is on the board of directors, 1946–47, and is a member of the following committees for 1946–47: Edison Medal, executive, and Standards and was chairman of the committee on inter-American engineering co-operation and AIEE representative on the Joint Committee on Inter-American Engineering Co-operation.

Davis, Buckley, LeClair, Danner and Terrell Are Nominated for Vice-Presidents

Ernest Walter Davis (A '15, M '21, F '34) chief electrical engineer, Simplex Wire and Cable Company, Cambridge, Mass., has been nominated as AIEE vice-president for the North Eastern District (1) for 1946–47. Mr. Davis was born March 3, 1890, in Auburn, Maine, and was graduated from the Massachusetts Institute of Technology in 1913 with the degree of bachelor of science. Immediately thereafter he entered the employ of the Simplex Wire and Cable Company as assistant electrical engineer. In this capacity he assisted in carrying on the general electrical engineering work connected with the manufacture of insulated wires and was instrumental in the development of the manufacture of high-voltage paper cables. He conducted an extended research of the properties of the steel taped cables. In 1932 Mr. Davis was promoted to the position of electrical engineer. He has had seven years' experience teaching in industrial evening schools, including three years as instructor in electrical engineering at the Franklin Union Evening School, Boston, Mass., and has served as chairman of an advisory committee on the study of dielectrics for the electrical engineering department of the Massachusetts Institute of Technology, Cambridge. He served as president of the Insulated Power Cable Engineers Association in 1933. He is the author of many papers and articles and has prepared written discussions on various cable papers presented at AIEE meetings. He has served on the following AIEE committees: applications to marine work, 1939–40, and power transmission and distribution, 1939–43.

Oliver Ellsworth Buckley (M '19, F '29) president, Bell Telephone Laboratories, Inc., New York, N. Y., has been nominated as AIEE vice-president for the New York District (3). Mr. Buckley was born in Sloan, Iowa, August 8, 1887, and received a bachelor of science degree from Grinnell College in 1909 and a doctor of philosophy degree from Cornell University in 1914. After a year's service as instructor in physics, Grinnell (Iowa) College, he went to Cornell University, Ithaca, N. Y., as assistant and then as instructor in physics (1912–14). For the next three years he worked in the engineering department of the Western Electric Company, New York, N. Y. During World War I he served as major in the United States Signal Corps. In 1919 he returned to the Western Electric Company as a member of the technical staff in the engineering department. From 1925 until 1928 he was a member of the technical staff, Bell Telephone Laboratories, Inc., New York, N. Y., and in the latter year became assistant director of re-

search. He became director of research in 1933, executive vice-president in 1937, and president in 1940. Mr. Buckley is the author of several technical articles and papers and holds many patents. He has been active in AIEE affairs and has been a member of the following committees: electrophysics, 1926–37, chairman, 1929–31; meetings and papers, 1929–31; research, 1934–40; Charles LeGeyt Fortescue fellowship, 1939–45, chairman 1941–45; Edison Medal, 1944–49; and technical program, 1946–47.

J. F. Fairman

T. G. LeClair

Conway

O. E. Buckley

Charles Foster Terrell (A '10, M '18) vice-president, Puget Sound Power and Light Company, Seattle, Wash., has been nominated as AIEE vice-president for the North West District (9). Mr. Terrell was born in Jerseyville, Ill., May 1, 1885, and received a bachelor of science degree in electrical engineering from the University of Washington in 1910. For six years from 1903 to 1909 while he was a student at the University of Washington he was substation operator of the Seattle Electric Company. Later he was load dispatcher, supervisor of boiler room practice, and from 1911 to 1913 he was general foreman of substation construction of the Seattle Electric Company and of the Puget Sound Traction, Light, and Power Company when the latter was formed in 1912. Subsequently, Mr. Terrell was substation construction engineer, superintendent of substations of the Puget Sound Traction, Light, and Power Company and in 1916 was appointed superintendent of transportation in charge of operation, maintenance, and construction of all substations operated by the company in Seattle and in smaller cities of the Puget Sound district. In 1922 he was named superintendent of light and power for the company's northwest division, Bellingham, Wash. Two years later Mr. Terrell was made superintendent of light and power of the El Paso (Tex.) Electric Company. Later he joined the staff of the Tampa (Fla.) Electric Company as general superintendent. In 1929 he became identified with the Gulf States Utilities Company, Beaumont, Tex., and was serving as operating manager when in 1941 he was appointed operating manager of the Puget Sound Power and Light Company. He became vice-president in 1944. Mr. Terrell served for two years, 1916 and 1917 as secretary of the AIEE Seattle Section.

Titus George LeClair (A '24, M '29, F '40) staff engineer, Commonwealth Edison Company, Chicago, Ill., has been nominated as AIEE vice-president for the Great Lakes District (5). He was born in Superior, Wis., August 26, 1899, and was graduated from the University of Idaho in 1921 with a bachelor of science degree in electrical engineering. After one year in the test course of the General Electric Company, Schenectady, N. Y., he became associated with the Commonwealth Edison Company as cable engineer. Subsequently he was substation field engineer (1924–27); engineer of system protection (1927–30); engineer, electrical engineer's office (1930–32); and development engineer (1932–36). He was appointed supervising development engineer in 1936 and recently was appointed staff engineer. Mr. LeClair has several relaying and control inventions to his credit. He has presented various papers before the AIEE conventions and Section meetings and has been generally active in Institute affairs. He was a director, 1941–45, and has served on many committees. They include the following: special committee on registration of engineers, 1942–47; planning and co-ordination, 1943–47; constitution and bylaws, 1944–47; Edison Medal, 1942–44; Standards, 1942–43; technical program 1942–43; and committee on Student Branches 1946–47. Mr. LeClair has been a member and trustee of the Western Society of Engineers, member of the Illinois Society of Engineers, and a director of the Illinois Engineering Council.

Ronald Fackler Danner (A '29, M '34, F '45) general superintendent, Oklahoma Gas and Electric Company, Oklahoma City, has been nominated as AIEE vice-president for the South West District (7). Mr. Danner was born in Astoria, Ill., November 2, 1897, and was graduated from the University of Oklahoma with a bachelor of science degree in electrical engineering in 1920. After a short period as electrical engineer with a consulting engineering firm in Oklahoma City, he entered the employ of the Oklahoma Gas and Electric Company in 1921 as electrical distribution engineer. A year later he was made assistant superintendent of the electrical department in charge of distribution system engineering. From 1923 to 1926 he was assistant to the general superintendent working in the capacity of assistant engineer, and in 1926 he was appointed general superintendent with supervision of the company's electrical engineering and operating departments. He has served as a member of the foreign systems committee of the National Electric Light Association, and when the Edison Electric Institute was organized he became a member of its transmission and distribution committee and served on important subcommittees of that committee. In 1937 and 1938 he was secretary of the Oklahoma Society of Professional Engineers. Mr. Danner was a member of the AIEE committee on power transmission and distribution, 1940–45. He has served on various local committees of the Oklahoma City Section and was vice-chairman and chairman of that Section for the years 1932–33 and 1933–34, respectively.

Grady

C. F. Terrell

Marquis

R. F. Danner

Bachrach

E. W. Davis

Fairman, Henry, Yerkes Nominated for Directorships

James Ferdinand Fairman (A '20, M '27, F '35) vice-president in charge of production and operation, Consolidated Edison Company of New York (N. Y.), has been nominated to serve on the AIEE board of

L. B. Chubbuck

R. T. Henry

Bachrach

E. P. Yerkes

directors. Mr. Fairman received the degrees of bachelor of science in electrical engineering (1918) and master of science (1921) from the University of Michigan. In 1925 he joined the Brooklyn (N. Y.) Edison Company. Following the merger of various companies into the Consolidated Edison Company he became electrical engineer for the system. In 1941 he was appointed assistant vice-president for design, inventory, purchasing, and stores. He was appointed vice-president in 1946. Mr. Fairman has been very active in Institute affairs and has served on many committees. He was AIEE vice-president for the New York, N. Y., District (3) for 1944–45. For further biographical details see *Electrical Engineering*, February 1946, page 85, and March 1944, page 110.

Raymond T. Henry (A '24, M '29, F '33) chief electrical engineer, engineering department, Buffalo (N. Y.), Niagara, and Eastern Power Company, has been nominated to serve on the AIEE board of directors. He has served the Niagara Falls (N. Y.) Hydraulic Power and Manufacturing Company, Hooker Electrochemical Company, Niagara Falls; Edison Illuminating Company, Detroit, Mich., and the Niagara Electric Service Corporation. He has been electrical engineer and assistant chief electrical engineer for the Buffalo, Niagara, and Eastern company. Mr. Henry has been active in Institute affairs and has served on many committees. He was awarded the 1933 AIEE national prize for the best paper on engineering practice. For further biographical data see *Electrical Engineering*, September 1945, page 335, and March 1944, page 110.

Earle Pierce Yerkes (A '15, F '40) engineer of equipment and buildings, Eastern area, Bell Telephone Company of Pennsylvania, Philadelphia, has been nominated to serve on the AIEE board of directors. Mr. Yerkes was born in Chester County, Pa., May 28, 1892, and was graduated from the University of Pennsylvania (1912) with a bachelor of science degree in electrical engineering. For two years after graduation he was student engineer with the Bell Telephone Company of Pennsylvania, and successively was specification writer, supervising specification writer, and engineering assistant, and in 1920 he became assistant engineer. From 1922 to 1925 Mr. Yerkes held the position of superintendent of machine switching equipment, and for the next two years he served as division superintendent of equipment. Subsequently, he was plant supervisor, superintendent of buildings and supplies, and engineer of equipment and in 1933 was appointed engineer of equipment and buildings. In 1938 he was detached temporarily from his regular assignment to take responsibility for inventory and appraisal of entire office, private branch exchange, and telephone station plant of the Bell Telephone Company of Pennsylvania. Mr. Yerkes has taken an active part in AIEE affairs. He is a member of the following committees: membership, 1942–47; communication, 1942–47; and special committee on collective bargaining and related matters, 1944–47.

L. B. Chubbuck (A '18, M '26, F '43) formerly assistant chief engineer, Canadian Westinghouse Company, Ltd., Hamilton, Ontario, has been appointed consulting engineer of the company. Mr. Chubbuck was born in November 1879 in Ottawa, Ontario, Canada, was graduated from the University of Toronto in 1899, and later received the degree of electrical engineer. He spent the nine years succeeding his graduation with the Westinghouse Electric Corporation, East Pittsburgh, Pa., on general switching equipment and in 1909 was transferred to the Canadian Westinghouse company as engineer in charge of switching equipment and in this position was a pioneer in the development of metal-clad switchgear. He was appointed assistant chief engineer in 1936. Mr. Chubbuck has been the author of several papers on switching equipment and is a past chairman of the Toronto Section and was AIEE vice-president for 1931–33.

E. F. Carter (A '25) director of industrial relations since 1941, Sylvania Electric Products, Inc., New York, N. Y., has been elected a vice-president in charge of industrial relations. Mr. Carter joined the company in 1932.

E. T. B. Gross (A '34, M '40) formerly assistant professor of electrical engineering, College of Engineering, Cornell University, Ithaca, N. Y., has been appointed professor of electric power system enigineerng, Illinois Institute of Technology, Chicago. Born in Vienna, Austria, in 1901, Doctor Gross received the degrees of electrical engineer in 1923 and doctor of technical sciences in 1932 from the University of Vienna. Prior to his entering the United States in 1939, Doctor Gross was an instructor at the Institute of Technology, Vienna (1921–24) and had been associated with AEG Union Electric and Manufacturing Company in Vienna from 1924 to 1938 and after 1938 with the British Company in London, England. He joined the staff of Cornell University as research associate in 1940, and, after a period as instructor of electrical engineering at the College of the City of New York (N. Y.), he returned to Cornell as assistant professor of electrical engineering in 1942. Doctor Gross served as consultant to the United States War Department from 1942 to 1944. He holds a number of patents and is the author of technical papers. He served as chairman of the section on high voltage systems protection and grounding at the International Conference on Large High Voltage Power Systems in 1937. Since 1940 he has been active in AIEE Section and Branch affairs and on technical groups.

L. W. Morton (A '38) formerly application engineer on power rectifiers, industrial engineering divisions, General Electric Company, Schenectady, N. Y., has been appointed head of the new power electronics division of the company. Mr. Morton, a graduate of the University of Minnesota, joined the General Electric Company in 1924 as a student engineer and has been application engineer since 1941.

M. A. deFerranti (M '43) formerly assistant chief, aerodynamics department, research laboratory, Curtiss Wright Corporation, Buffalo, N. Y., has been named engineer of the new materials handling and testing equipment division of the General Electric Company. Mr. deFerranti, a graduate of the Sydney Technical School and a former employee of the Australian General Electric Company, Ltd., was first associated with the General Electric Company in 1929. Later that year he was transferred to the International General Electric Company, returning to Schenectady as application engineer. From 1943 until his return to the General Electric Company in 1945 he was employed by the Curtiss-Wright Corporation.

E. L. Bowles (A '22, F '33) expert consultant to the United States Secretary of War and communications consultant to the commanding general, Army Air Forces, recently was awarded the Distinguished Service Medal for his services to the Army Air Forces. Doctor Bowles was commended for organizing an advisory group composed

of electronics specialists, for securing the aid of leaders in scientific and industrial laboratories, and for placing scientific personnel on the staffs of all major AAF commands. Doctor Bowles, who has been on leave of absence as professor of electrical communications, Massachusetts Institute of Technology, Cambridge, since 1942, was particularly concerned with plans for the antisubmarine warfare in the Atlantic and for combating the "buzz bomb" assaults in England. In 1945 Doctor Bowles also was awarded the honorary degree of doctor of science by Norwich University, Norfolk, England.

L. J. Linde (A '39, M '45) formerly assistant to the managing engineer of the power circuit breaker division, General Electric Company, Philadelphia, Pa., has been appointed chief engineer of the A. B. Chance Company, Centralia, Mo. Mr. Linde holds the bachelor of science degree in mechanical engineering from South Dakota State College. He entered the employ of the General Electric Company in 1929 as student engineer and was named design draftsman in 1930 and design engineer in 1932. As design engineer and development engineer, which he became in 1937, he was twice the recipient of a joint Charles A. Coffin Award of Merit, the first for work on an a-c network protector, and the second for development of the Magne-blast oilless circuit breaker. Mr. Linde was made assistant to the managing engineer of the power circuit breaker division in 1941.

F. H. King (A '31, M '40) who has been provisional manager of the Holyoke (Mass.) Gas and Electric Department since October 1945, has been appointed manager. Mr. King, a 1928 graduate of Worcester Polytechnic Institute, entered the Holyoke department as a draftsman in 1931. He was named electrical engineer in 1932 and assistant superintendent of the electric station in 1933. In 1937 he was loaned to the Electric Light Department of the City of Burlington, Vt., and continued as superintendent of that department until in 1941 he was appointed power consultant on the staff of the power division of the Office of Production Management. He served on the Army and Navy Munitions Board in 1942 and later, as a lieutenant colonel, was chief of the electronics section of the resources division at Army Air Forces headquarters.

A. G. Grier (A '04) manager, distribution equipment division, Canadian General Electric Company, Ltd., Toronto, Ontario, Canada, has retired. Mr. Grier was born in Ottawa, Ontario, in 1878 and was graduated from McGill University in 1899 with the degree of bachelor of science. In 1901 he received the degree of master of science. Early in his career Mr. Grier was associated for short periods with the Stanley Electric Company, the Western Electric Company, Allis-Chalmers Manufacturing Company in the United States, and the Royal Electric Company of Montreal, Quebec, Canada. In 1906 he became partner in the firm of Wescott and Grier, Montreal, and from 1911 to 1919 practiced engineering in Peterboro, Ontario. He joined the Canadian General Electric Company, Peterboro, in 1920 as assistant to the general superintendent. In 1926 he was named distribution engineer.

V. W. Bergenthal (A '01) treasurer and director, Wagner Electric Corporation, St. Louis, Mo., retired December 31, 1945 but will continue to serve as a director. A native of Milwaukee, Wis., Mr. Bergenthal received from the University of Wisconsin a bachelor of science degree in electrical engineering (1897) and the degree of electrical engineer (1898). In the latter year he entered the engineering department of Stanley Electric Manufacturing Company, Pittsfield, Mass. He went to California in 1900 as assistant engineer of the Bay Counties Power Company. He returned to the Stanley company in Pittsfield and was placed in charge of transformer design. In 1901 he went to the Chicago (Ill.) office and in 1903 was appointed assistant manager. Later in 1903 he became electrical engineer and secretary, American Automatic Switch and Signal Company, Chicago, Ill. In 1904 Mr. Bergenthal joined the staff of the Wagner Electric Company and has served as manager, purchasing agent, treasurer, and treasurer and director.

L. M. Smith (M '36) director of public relations, Alabama Power Company, Birmingham, has been elected a vice-president of the company. Mr. Smith was graduated from the University of Alabama with the degree of bachelor of science in 1916 and for a time was employed by the Navy Department at Norfolk, Va., and by the Tennessee Coal, Iron, and Railroad Company, Birmingham. From 1923 to 1931 he was associated with the Dixie Construction Company and it successor, Allied Engineers, Inc., Birmingham, and in this connection supervised the construction for the properties of the Commonwealth and Southern Corporation in six southern states. In 1931 he joined the Alabama Power Company as electrical engineer and in 1937 was given the title chief engineer. He became director of public relations in 1944.

J. C. Peet (A '08, M '22) chairman of the electrical engineering department, Newark College of Engineering, Newark, N. J., has retired. Professor Peet was born in Webster, N. Y., in 1880, and was graduated from Syracuse University with the degree of electrical engineer in 1903. After a short time with the General Electric Company, Schenectady, N. Y., he turned to teaching at the Mechanics Institute, Rochester, N. J., from 1907 to 1910, and at the Harrisburg (Pa.) Technical High School from 1910 to 1917. He became professor of physics at Toledo (Ohio) University in 1917 and in 1918, at the inception of the Newark College of Engineering, assumed the chairmanship of the electrical engineering department. Professor Peet is a member of the Society for the Promotion of Engineering Education and Tau Beta Pi.

A. A. Nims (A '11, M '28) professor of electrical engineering, Newark College of Engineering, Newark, N. J., has been elected chairman of the electrical engineering department of the college. Born in Montague, Mass., in 1886, Professor Nims was graduated from Worcester Polytechnic Institute in 1908. After graduation he was for a time instructor at the Institute. His industrial experience includes work with the Murphy Electricity Rectifier Company, Rochester, N. Y., in 1911; a period with the Crocker-Wheeler Company, Ampere, N. J., from 1912 to 1919; and one with the Siemund-Wenzel Electric Welding Company, New York, N. Y., from 1919 to 1922. In 1922 he joined the faculty of the Newark College of Engineering as instructor, becoming assistant professor in 1924, and associate professor in 1926. He was named full professor in 1932.

K. V. Farmer (M '21) formerly general manager of the Canadian Ohio Brass Company, Ltd., Niagara Falls, Ontario, has been elected a vice-president of the company. Mr. Farmer, who was born in Newark, Ohio, and was graduated from Swarthmore College, was associated with the Syracuse (N. Y.) Lighting Company from 1913 to 1924 at first in the meter, distribution, and production departments. In 1916 he was placed in charge of the completion of duct system and substations. He became assistant to the superintendent of the electric department in 1917, assistant superintendent in 1918, and superintendent in 1922. After a short period with the Ohio Insulator Company, Barberton, he joined the Ohio Brass Company, Mansfield, in 1925 and was named district engineer in 1927. About 1933 he became manager of the Canadian Ohio Brass Company.

I. C. Smith (A '30) engineer of the d-c engineering department, Crocker-Wheeler division, Joshua Hendy Iron Works, Ampere, N. J., has been appointed chief engineer of the company. Mr. Smith, who was born in St. Philip de Chester, Quebec, Canada, in 1899, received the degrees of bachelor of arts in 1920 and electrical engineering in 1922 from Cornell University. Mr. Smith commenced his career as design engineer with the Westinghouse Electric Corporation in 1922. He continued his work on d-c machine design when he became associated with the Elliott Company, Reading, Pa., in 1930, and in 1939 he assumed charge of that work for the company. In 1942 he joined the Crocker-Wheeler Company.

J. F. Rider (A '28) recently lieutenant colonel in the Army Signal Corps, and president of John F. Rider, Publisher, Inc.,

New York, N. Y., has been presented with the Legion of Merit medal. The citation for Colonel Rider, who spent 3½ years in military service, read in part ". . . rendered exceptional administrative service to the Signal Corps publication agency. . . . His ability to organize and utilize effectively available personnel materially contributed to the preparation, production, and distribution of vitally needed technical manuals containing instruction for the installation, operation, maintenance, and repair of signal equipment."

G. J. Irwin (A '44) formerly chief engineer, Philco Corporation of Canada, Toronto, Ontario, is now engineer, radio division, Royce Avenue works, Canadian General Electric Company, Ltd., Toronto. Born in Toronto in 1905, Mr. Irwin's first engineering position was that of laboratory assistant for the De Forest Crossley Radio Company, Toronto, in 1929. He was assistant engineer with the Williams Piano Company, Oshawa, from 1930 until in 1932 he became assistant engineer for the Philco corporation. He had been chief engineer since 1935. Mr. Irwin is vice-chairman of the engineering committee of the Radio Manufacturers' Association of Canada, coordinator of the Canadian Radio Technical Planning Board, and a representative of the radio industry on the main committee of the Canadian Standards Association.

W. L. Widlar, Jr. (A '43) project engineer for the Mec-Rad division of Black Industries, Cleveland, Ohio, since November 1944, has been appointed general manager of that division. From 1933 to 1943 he was radio research engineer for WGAR Broadcasting Company, Cleveland, except when he was on leave of absence in 1942 to serve as research engineer member in New London, Conn., and New York, N. Y., of the laboratory staff of Columbia University's division of war research. In 1943 he became part-time research engineer for the Bird Engineering Company, Cleveland.

W. D. Coolidge (A '10, M '34) retired vice-president and director of research, General Electric Company, Schenectady, N. Y., and who recently has been touring South America, has been awarded the Order of Merit of the Chilean Government. Doctor Coolidge has received many honors, including Edison Medal, Faraday Medal, Franklin Institute Medal, and Washington Award. He has served on AIEE committees, including: electrophysics, 1927–29; Edison Medal, 1940–45; and applications of electricity to therapeutics, 1941–46.

F. E. Nutt (A '36) formerly Washington (D. C.) representative, Crocker-Wheeler Electric Manufacturing Company, has been named assistant sales manager, division of the company's Joshua Hendy Iron Works, Ampere, N. J. Mr. Nutt is a graduate of the University of Denver (1931) with a bachelor of science degree in electrical engineering. Since 1942 he has been associated with Crocker-Wheeler sales.

F. H. Pumphrey (M '25) is now educational service engineer, educational service division, General Electric Company, Schenectady, N. Y. He served as a lieutenant colonel, Signal Corps, Army of the United States, during World War II and prior to his receiving his commission, was professor of electrical engineering, Rutgers University, New Brunswick, N. J. He was a member of the AIEE communication committee, 1932–36, and publication committee, 1941–44.

W. J. Lind (A '36) formerly lighting service engineer, lamp and lighting division, Canadian General Electric Company Limited, Vancouver, British Columbia, has been made manager of that division. A graduate in mechanical engineering from the University of British Columbia, Mr. Lind joined the Canadian General Electric in 1937 after serving in the department of mechanical and electrical engineering as an instructor and lecturer at the University of British Columbia.

M. F. Beisber (A '37) transformer specialist for the Line Material Company on the West Coast, has been appointed sales manager of the transformer division of the company, Milwaukee, Wis., with headquarters in Zanesville, Ohio. He joined the sales organization of the company in 1933 as field engineer for the Memphis (Tenn.) district. In 1941 he went to the San Francisco (Calif.) office.

L. J. Olivier (A '39) superintendent, transformers and stores department, Louisiana Power and Light Company, New Orleans, is now with the Graybar Electric Company, New Orleans, as merchandising manager. Mr. Olivier became associated with the Louisiana Power and Light Company in 1927.

G. A. Loveless (A '28, M '36) formerly manager, instrument division, Sangamo Electric Company, Springfield, Ill., has been named district manager, north central district, with headquarters in Minneapolis, Minn. Mr. Loveless is a graduate of Washington University with a bachelor of science degree in electrical engineering. He was a member of the AIEE membership committee, 1937–38.

OBITUARY • • • •

Frank Fuller Fowle (A '02, M '12) head of the consulting engineering firm, Frank F. Fowle and Company, Chicago, Ill., died January 21, 1946. Born in San Francisco, Calif., November 29, 1877, Mr. Fowle received the degree of bachelor of science from Massachusetts Institute of Technology in 1899. In his first position from 1899 to 1903 as assistant electrician in the engineering department of the American Telephone and Telegraph Company, New York, N. Y., Mr. Fowle was active in the development of the Pupin loading system. In 1903 he was made special agent in the company's railway department and was one of the pioneers in the introduction of the telephone for railway dispatching. He became manager of the Chicago operating territory of the company's long-distance system in 1906. He was a consultant in Chicago from 1908 to 1912, then going to New York, as associate editor of *Electrical World* for one year and as consulting engineer for one year. He was named receiver of the Central Union Telephone Company in 1914. He was a member of the firm of Fowle and Cravath, Chicago, in 1919 and 1920, and in 1920 became head of the firm, Frank F. Fowle and Company. Mr. Fowle was author of many technical papers and articles and had been editor in chief of the "Standard Handbook for Electrical Engineers" since 1913. He was an AIEE manager from 1919 to 1923, served as president of the Western Society of Engineers in 1935 and 1936 and as president of the Illinois Engineering Council. He was also a member of the Illuminating Engineering Society, the American Society for Testing Materials, the Association of American Railroads, and the American Society for Metals. Active in community affairs, Mr. Fowle had served on the Winnetka, Ill., Board of Education, the Winnetka Zoning Commission, and the Zoning Board of Appeals. He was consulting engineer to the National Electric Light Association from 1920 to 1932.

Hugh Alexander Laidlaw (A '09, M '36) assistant engineer of operation, Pacific Gas and Electric Company, San Francisco, Calif., died December 15, 1945. Mr. Laidlaw was born in Portland, Oreg., March 20, 1880. He commenced his electrical career with the Portland General Electric Company, later the Portland Railway Light and Power Company, with which he was associated from 1898 to 1907 as shop apprentice, as member of the street lighting department and meter department, as station operator, inspector, chief inspector, and as assistant to the chief electrical engineer. In 1907 he went to Nome, Alaska, as general superintendent of the Nome Electric Light and Power Company. He entered the employ of the Pacific Gas and Electric Company as engineering assistant to the chief electrical engineer and was named assistant engineer of operation in 1923.

William Germain Vincent (A '05) vice-president and executive engineer, Pacific Gas and Electric Company, San Francisco, Calif., died January 29, 1946. Mr. Vincent was born August 11, 1882, in New Orleans, La., and held the degrees of bachelor of engineering from Tulane University of Louisiana (1902) and of mechanical engineer from Cornell University (1904). Mr. Vincent was associated with the Gray Telautograph Company from 1902 to 1906 in

New York, N. Y., and in San Francisco, Calif. After brief interludes with the Ocean Shore Railway Company, C. L. Cory, construction engineer, and J. G. White and Company, he joined the Pacific Gas and Electric Company in 1912, as valuation engineer. In 1922 he became vice-president and executive engineer. He was also a vice-president and member of the board of directors of the Standard Pacific Gas Line Company and a past president of the Engineers Club of San Francisco.

Baldwin Drew Ward (A '45) electrician, Oakland (Calif.) Army Base, died January 18, 1946. Mr. Ward was born in Lindly, N. Y., December 4, 1880. Mr. Ward gained his early experience in electrical contracting doing repair and installation work in New York, N. Y., Philadelphia, Pa., Detroit, Mich., and St. Louis, Mo. Before 1917 he worked as station operator and foreman for the St. Louis Signal and Power Company, the Fort Worth (Tex.) Signal and Power Company, Stone and Webster, Inc., the Pacific Signal and Power Company, and the Cowell-Portland Cement Company. From 1917 to 1920 he worked as subforeman for the Moore Shipbuilding Company, Oakland. Thereafter he operated as a licensed contractor in the state of California. In 1942 he became electrical inspector for the utilities and marine repair shop of the United States Army Engineers, Oakland. Mr. Ward was an AIEE Associate from 1911 to 1919 and from 1921 to 1924.

Edward Holder (A '13, M '44) formerly superintendent of metering, operating department, Shawinigan Water and Power Company, Montreal, Quebec, Canada, died December 20, 1945. Mr. Holder was born at Kingston, Surrey, England, May 30, 1888, and was graduated from the University of London in electrical engineering in 1908. His first job was assistant testing engineer, Newcastle (England) Electric Supply Company. In 1911 he went to Canada and was employed by the British Columbia Electric Railway Company, Vancouver, as district representative in the light and power department. In 1916 he enlisted in the Royal Canadian Engineers and after his discharge joined the staff of the Shawinigan company as meter engineer. In 1943 he was made superintendent of the meter division. Mr. Holder was chairman of the Canadian Electrical Standards Association's watt-hour meter committee and a member of the associate committee of the National Research Council on electrical measuring instruments.

Albert Raiguel Bingham (A '07, M '21) retired, general superintendent, Canadian Light and Power Company, St. Timothee, Quebec, Canada, died January 4, 1946. Mr. Bingham was born in Philadelphia, Pa., March 30, 1878, and was graduated from Drexel Institute of Technology in electrical engineering in 1900. He engaged in various enterprises early in his career, with D'Olier Engineering Company, electrical contractors of Philadelphia, an electrical contracting business of his own at Housatonic, Mass., with the Berkshire Street Railway, Housatonic, construction work on the power plant of the Monument Mills Company, Glendale, Mass., with the power plants of the Hudson River Electric Power Company at Utica and Spier Falls, N. Y., and from 1909 to 1913, with the power plant of the Aluminum Company of America, Massena, N. Y. In the latter year he began his association with the Canadian Light and Power Company as assistant superintendent. Later he was promoted to superintendent.

Clarence Albert Price (A '19, M '39) formerly chief engineer, Canadian Westinghouse Company, Ltd., Hamilton, Ontario, Canada, died December 29, 1945. Mr. Price was graduated as electrical engineer from Drexel Institute of Technology in 1898. For the first four years of his career he was general contractor on electrical work, with J. A. Roebling's Sons and with the Bell Telephone Company of Philadelphia (Pa.) on the electrolysis survey of underground cable. In 1902 he became associated with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., and in 1906 changed to the Canadian Westinghouse Company, Hamilton, in charge of induction motor and transformer design. He became assistant chief of the company in 1919 and in 1936 was appointed chief engineer. Mr. Price was AIEE vice-president for the District of Canada (10) from 1941 to 1943 and was an active member of the AIEE Toronto Section, having been chairman, 1934–35. He was also a member of the AIEE committee on Institute policy, 1941–42.

William August Petrasek (A '36) project engineer, American Airlines, Inc., LaGuardia Field, New York, N. Y., was killed in the crash of an airliner, January 31, 1946. Born July 16, 1914, in New York, Mr. Petrasek was graduated from New York University in 1935. He was employed as engineering draftsman and laboratory assistant by the Diehl Manufacturing Company, Elizabethport, N. J., until 1937 when he became assistant instructor of electrical engineering at New York University, New York. In 1940 he joined American Airlines as electrical engineer and was given the title project engineer in 1944. Mr. Petrasek was a member of the AIEE committee on air transportation. He was a member of Tau Beta Pi and had published an article in *Electrical Engineering* and technical papers in AIEE *Transactions*.

Myrick Whiting Pullen (A '07, M '29) associate in electrical engineering, Johns Hopkins University, Baltimore, Md., died January 10, 1946. Professor Pullen was born in Whiting, Iowa, January 25, 1883, and was graduated from the University of Iowa. He was an instructor at Iowa State College, Ames, from 1908 to 1910 and in the latter year joined the faculty of Johns Hopkins University as assistant in electrical engineering. He was named instructor in 1913 and associate in electrical engineering in 1920. Professor Pullen's research activities included work on formation of corona, the corona voltmeter, a memory testing machine, and development of a special circuit breaker. He also had done research work for the United States Bureau of Mines. He was a member of the AIEE committee on production and application of light from 1940 to 1943.

Henry Van deVere Putman (A '23, M '32) vice-president, Westinghouse Electric Corporation, Sharon, Pa., died January 16, 1946. Mr. Putman, who was born May 27, 1899, in Barker, N. Y., studied at Union College from which he received the degrees of bachelor of science, master of science, and doctor of philosophy. Before joining the Westinghouse Corporation as design engineer in 1925, Mr. Putman was design engineer and assistant chief engineer with the Ideal Electric Manufacturing Company, Mansfield, Ohio. He was named section engineer in 1928, and was transferred to Sharon, Pa., in 1929 as assistant manager of the transformer engineering department. He became manager of the department in 1931, and later manager of the division. In 1942 he was elected a vice-president. He had served on the AIEE committees on electric machinery and power transmission and distribution.

Arthur Francis Ward Richards (A '17, M '39) consulting engineer and member of the firm, Richards and Bright, London, England, died January 25, 1946. Mr. Richards was born September 1, 1877, in Bristol, England, and attended Haileybury College. He commenced his career with the Hastings Electric Light Works, London, in 1894 and became assistant engineer with the Reading Electric Light Works, London, in 1897. He was appointed assistant engineer for the County of London Electric Supply Company, Ltd., in 1901 and from 1906 to 1919 was engineer in the contract department of W. T. Glover and Company, Ltd., Manchester, England. Since 1919 he had practiced as a consulting engineer.

Wheeler Newman Voorhees (A '10) retired, General Electric Company, New York, N. Y., died January 18, 1946. Mr. Voorhees was born in Brooklyn, N. Y., January 20, 1870 and attended New York University. In 1889 he began work with the Westinghouse Electric and Manufacturing Company, Newark, N. J., and the following year he was employed by the Coney Island and Brooklyn Railroad Company. In 1900 Mr. Voorhees entered the employ of the General Electric Company as electrical construction foreman in charge of the company's reconstruction contract at the main station of the Metropolitan Street Railway Company. He was retired in 1932 after 32 years as a construction engineer.

MEMBERSHIP. . .

Recommended for Transfer

The board of examiners, at its meeting of February 21, 1946, recommended the following members for transfer to the grade of membership indicated. Any objections to these transfers should be filed at once with the secretary of the Institute.

To Grade of Fellow

Green, S., vice-pres. & chief engr., Aerovox Corp., New Bedford, Mass.
Hatch, P. H., general mech. supt., N. Y., N. H. & H. R. R. Co., New Haven, Conn.
Holliday, T. B., colonel, Air Corps, Wright Field, Dayton, Ohio.
Hughes, C. T., general supt., Connecticut Lt. & Pr. Co., Waterbury, Conn.
Sanford, F. E., supt., distribution engg., Cincinnati Gas & Elec. Co., Cincinnati, Ohio.
Simpson, W. L., chief elec. engr., Rio de Janeiro Tramway, Lt. & Pr. Co., Sao Paulo, Brazil, S. A.

6 to grade of Fellow

To Grade of Member

Andrews, G. E., Jr., distribution engr., Narragansett Elec. Co., Providence, R. I.
Augermann, W. B., asst. prof. of elec. engr., University of Southern California, Los Angeles, Calif.
Arnold, W. O., member of technical staff, Bell Tel. Labs., Inc., New York, N. Y.
Atkinson, J. F., assoc. elec. engr., Rural Electrification Administration, Washington, D. C.
Brennecke, C. G., prof. and head, dept. of elec. engg., North Carolina State College, Raleigh, N. C.
Bussard, J. H., radio engineer, Crosley Corp., Cincinnati, Ohio
Button, C. T., sales manager, Master Elec. Co., Dayton, Ohio
Cohen, R. L., elec. squad leader, E. I. duPont de Nemours, Wilmington, Del.
Farrer, H. E., asst. to secy., Standards Committee, Board of Examiners, AIEE, New York, N. Y.
Ferguson, J. P., cons. and application engr., Westinghouse Elec. Corp., San Francisco, Calif.
Fitch, H. S., general supt. of substations, West Penn Power Co., Pittsburgh, Pa.
Fredrick, E. B., application engr., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Greene, R. E., construction engr., Detroit Edison Co., Detroit, Mich.
Hanson, L. P., elec. engr., Boeing Aircraft Co., Seattle, Wash.
Hare, S. B., elec. engr. in charge of design, Sawyer Electrical Mfg. Co., Los Angeles, Calif.
Heinrich, H., engr., general const. dept., Hawaiian Elec. Co., Ltd., Honolulu, T. H.
Higgins, L., supt., service shop, General Elec. Co., Cincinnati, Ohio.
Janssens, J. N., director and acting general mgr., Automatique Electrique, Antwerp, Belgium
Jenkins, D. F. L., elec. engr., Messrs. Johnson & Phillips, Ltd., Charlton, London, Eng.
Jordan, W., 3d, asst. prof., dept. of elec. engg., Newark College of Engg., Newark, N. J.
Kuhlman, L. G., pres. and general mgr., Wadsworth Elec. Mfg. Co., Inc., Covington, Ky.
Lamberton, A. F., elec. engr., Taylor Instrument Cos., Rochester, N. Y.
Lloyd, R. L., assoc. elec. engr., National Bureau of Standards, Washington, D. C.
Marvin, G. S., experimental engr., General Motors Corp., Flint, Mich.
Morgan, S. C., prof. of elec. engg., University of British Columbia, Vancouver, B. C., Canada
Noy, J. M., elec. engr., Climax Molybdenum Co. of Pennsylvania, Langeloth, Pa.
Phares, J. A., Southwest Elec. Co., Oklahoma City, Okla.
Reid, C. R., elec. engr., Hoover Co., North Canton, Ohio
Rue, H. E., sr. elec. engr., Hoover Co., North Canton, Ohio
Scott, E. O., chief electrician and head of elec. dept., Ontario Bolt Metallurgical Co. of Canada, Ltd., Welland, Ont., Can.
Sheckels, G. D., asst. prof., dept. of elec. engg., Montana State College, Bozeman, Mont.
Smith, E. P., design engr., General Elec. Co., Schenectady, N. Y.
Smith, I. C., chief engr., Crocker-Wheeler Elec. Mfg. Co., Ampere, N. J.
Smith, R. M., elec. engr., Railway & Industrial Engg. Co., Greensburg, Pa.
Smrs, O. L., exec. vice-pres., Line Material Co., Milwaukee, Wis.
Sursanky, P., supt. of distribution, Pacific Gas & Elec. Co., Sacramento, Calif.
Wilhelm, H. T., member of tech. staff, Bell Tel. Labs., New York, N. Y.
Williams, N. A., elec. engr., Goodyear Tire & Rubber Co., Akron, Ohio
Williamson, E. T., vice-pres. chrg. of operation, Iowa-Illinois Gas & Elec. Co., Rock Island, Ill.
Zerwigen, M. G., assoc. prof. of elec. engg., Tulane Univ., New Orleans, La.

40 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Any member objecting to the election of any of these candidates should so inform the secretary before April 15, 1946, or June 15, 1946, if the applicant resides outside of the United States or Canada.

To Grade of Member

Allleret, P. J., "Ecole Nationale des Ponts & Chaussees," Paris, France
Barnes, T. G., College of Mines and Metallurgy, El Paso, Tex.
Blankenburg, R. C., Southern California Edison Co., Ltd., Los Angeles, Calif.
Bourhill, D. A., Dunoon & District Electricity Supply Co., Ltd., Dunoon, Scotland
Briggs, D. K., Western Elec. Co., Kearny, N. J.
Burnham, A. H., Locke Insulator Corp., Baltimore, Md.
Cain, D. E., General Elec. Co., St. Louis, Mo.
Carey, J. J., University of Kansas, Lawrence, Kan.
Condit, S. B., The Chase-Shawmut Co., Boston, Mass.
Eldridge, L. C., Baton Rouge Water Works Co., Baton Rouge, La.
Friday, C. D., Bureau of Yards & Docks, Navy Dept., Washington, D. C.
Galle, P. F., Tennessee Eastman Co., Oak Ridge, Tenn.
Goldbach, L. A., Cleveland Switchboard Co., Cleveland, Ohio
Healy, H., Tennessee Eastman Corp. (CEW), Oak Ridge, Tenn.
Hietala, A. A., Public Service Elec. and Gas Co., Newark, N. J.
Hope, J., R. H. Bouligny, Inc., Charlotte, N. C.
Horney, M. J., Kansas City Power & Light Co., Kansas City, Mo.
Irwin, K. M., Philadelphia Elec. Co., Philadelphia, Pa.
James, V. E., Automatic Elec. Co., Chicago, Ill.
Johnson, F. C., Gibbs & Hill, Inc., New York, N. Y.
Jones, E. F., United Engineers & Constructors, Inc., Philadelphia, Pa.
Kelrin, G., West Virginia Pulp and Paper Co., Charleston, S. C.
Kirk, H. P., Artcraft Elec. Supply Co., Wilmington, Del.
Kroesen, O. M., Tennessee Valley Authority, Knoxville, Tenn.
Leedy, H. A., Armour Research Foundation, Chicago, Ill.
Liming, C. A., Public Service Co. of Okla., Tulsa, Okla.
Machler, R. C., Leeds & Northrup, Philadelphia, Pa.
MacIsaac, W. A., N. S. Dept. of Mines, Glace Bay, N. S.
Malloch, C. D., Consumers Power Co., Jackson, Mich.
Mehtani, Y. S., Karelabagh Pumping Station, Allahabad, UP, India
Meyer, H. L., Consumers Public Power District, York, Nebr.
Mukherji, R. G., Govt. of Bengal, Dacca, Bengal, India
Murton, D. R., Commonwealth and Southern Corp., Birmingham, Ala.
Neblett, W. R., The Commonwealth & Southern Corp., Jackson, Mich.
Oldham, A., Federal Wire & Cable Co., Ltd., Guelph, Ont., Canada
Peebles, F. D., REA, Dept. of Agriculture, Washington, D. C.
Prier, J. D., General Elec. Co., Schenectady, N. Y.
Purandare, D. N., Western India Engg. Corp., Ltd., Bombay, India
Rankin, J. A., Belmont Radio Corp., Chicago, Ill.
Reineck, H., Veltronic Company, Detroit, Mich.
Rodgers, E. J., Bureau of Ships, Navy Dept., Washington, D. C.
Saitzoff, A. M., MacDonald International, Inc., New York, N. Y.
Seshadri, B., % National Physical Laboratory, Teddington, England
Skinner, M. E. (Re-election), Buffalo Niagara Elec. Corp., Buffalo, N. Y.
Sommers, O. W., City Public Service Board, San Antonio, Tex.
Stoner, K. W., Corn Products Refining Co., Chicago, Ill.
Tornno, M. G., Merritt-Chapman & Scott, New York, N. Y.
Tour, G. I. (Re-election,) Tennessee Valley Authority, Knoxville, Tenn.
Trowbridge, C. A., Commercial Solvents Corp., Terre Haute, Ind.
Tse, P-Y., Sin Chung Engineering Co., Shanghai, China
VanDkye, E. R., General Elec. Co., Atlanta, Ga.
Wadia, M. H., Capt. I. E. Royal Engineers, Coimbatore, South India
Wojcik, T. M., General Cable Corp., Rome, N. Y.
Wray, J. Q., Jr., Pennsylvania Water & Power Co., Baltimore, Md.
Wray, P. M., Wray Elec. Contracting, Inc., Cincinnati, Ohio
Wylie, R. R., Rumsey Elec. Co., Roanoke, Va.

56 to grade of Member

To Grade of Associate

United States and Canada

1. North Eastern

Ackerman, C. J., Lieut. Comdr., USNR, Office of the Resident Inspector of Naval Material, Syracuse, N. Y.
Armor, P. C., Brown University, Providence, R. I.
Blumenthal, I. S., General Elec. Co., Bridgeport, Conn.
Brennan, J. J., Ens., SC, USNR, Harvard Univ., Cambridge, Mass.
Brohl, E. M., Bendix Aviation Co., Norwood, Mass.
Bundy, R. C., Chance Vought Aircraft, Stratford, Conn.
Burns, R. C., SoundScriber Corp., New Haven, Conn.
Cole, B. T. (Re-election), Westinghouse Elec. Corp., Buffalo, N. Y.
Crook, C. W., Eastman Kodak Co., Rochester, N. Y.
Davidson, J. M., Electro Metallurgical Co., Niagara Falls, N. Y.
deWolf, G. L., General Elec. Co., Syracuse, N. Y.
DiNozzi, A. D., Raytheon Mfg. Co., Waltham, Mass.
Flint, G. E., The Derby Gas and Elec. Co., Derby, Conn.
Hutchings, F. F. (Re-election), Veterans Administration, Boston, Mass.
Johnson, A. H., Bell Aircraft Corp., Niagara Falls, N. Y.
Kelliway, B. J., General Elec. Co., Schenectady, N. Y.
Korona, F. S., Buffalo Niagara Elec. Corp., Buffalo, N. Y.
Littleton, J. C., Corning Glass Works, Corning, N. Y.
Lowderback, C. J., 1092 Blue Hills Ave., Bloomfield, Conn.
Najarian, A. A., Royal Elec. Co., Inc., Pawtucket, R. I.
Neagle, N. M., General Elec. Co., Boston, Mass.
Rademaker, L. C., Jr., General Elec. Co., Schenectady, N. Y.
Russell, F. A., Chas. T. Main, Inc., Boston, Mass.
Sallba, A. C., General Elec. Co., Pittsfield, Mass.
Santa, M. M., Massachusetts Institute of Technology, Cambridge, Mass.
Sechrist, H. S., General Elec. Co., Schenectady, N. Y.
Simkins, W. C. G., Chas. T. Main, Inc., Boston, Mass.
Spehr, C. J., General Elec. Co., Schenectady, N. Y.
Stauffer, J. R., Philadelphia Elec. Co., Phila., Pa.
Sun, S-S., Massachusetts Institute of Technology, Cambridge, Mass.
Taylor, F. C., Narragansett Elec. Co., Providence, R. I.
Teich, F. J., General Elec. Co., Schenectady, N. Y.
Templeton, D. E., Electro Metallurgical Co., Niagara Falls, N. Y.
Weller, B. L., Remington Arms Co., Inc., Bridgeport, Conn.
White, G. M., General Elec. Co., Schenectady, N. Y.

2. Middle Eastern

Ader, C. M., Sr., Bethlehem Steel Co., Baltimore, Md.
Audi, J. M., Line Material Co., Zanesville, Ohio
Bellizzi, J. A., Lt., USNR, Naval Research Lab., Washington, D. C.
Blalock, V. (Mrs.), Day & Zimmermann, Inc., Philadelphia, Pa.
Brandt, D. P. (re-election), United Engineers & Constructors, Inc., Philadelphia, Pa.
Caplan, A. G., Duquesne Light Co., Pittsburgh, Pa.
Carlson, F. L., REA, Dept. of Agriculture, Washington, D. C.
Cavender, G. L., Pennsylvania Coal Products Co., Petrolia, Pa.
Crim, H. C., War Dept., Wright Field, Dayton, Ohio
Davis, E. T., Leeds & Northrup Co., Philadelphia, Pa.
Dietrich, W. K., Bethlehem Steel Co., Baltimore, Md.
Farkas, E. C., Reliance Elec. & Engg. Co., Cleveland, Ohio
Fibich, H. G., National Acme Co., Cleveland, Ohio
Garrett, G. S., Engineering Products Co., Charleston, W. Va.
Giordano, J. J., Westinghouse Elec. Corp., E. Pittsburgh, Pa.
Cross, W., Philadelphia Elec. Co., Philadelphia, Pa.
Gutierrez, G., Westinghouse Elec. Corp., E. Pittsburgh, Pa.
Hammel, R. T., Dist. of Columbia Govt., Washington, D. C.
Heller, J. H., U. S. Army Signal Corps, Lansford, Pa.
Hnyla, J., The Maryland Drydock Co., Baltimore, Md.
Irwin, C. B., Jr., Consolidated Gas Elec. Light & Power Co. of Baltimore, Baltimore, Md.
Jenner, W. C., Reliance Elec. & Engg. Co., Cleveland, Ohio
Kepner, J. W., Appalachian Elec. Power Co., Cabin Creek, W. Va.
Kimball, B. L., Sperry Gyroscope Co., Inc., Baltimore, Md.
Machuga, M. A., Aberdeen Proving Ground, Md.
Martin, J. W., Naval Ordnance Lab., Washington, D. C.
Merkel, H. E., U. S. Treasury Dept., Washington, D. C.
Perris, L., United Engineers & Constructors, Inc., Philadelphia, Pa.
Poe, H. V., Westinghouse Elec. Corp., E. Pittsburgh, Pa.
Pratt, J. M., Bull Dog Elec. Products Co., Cincinnati, Ohio

Pryor, H., The Elec. Storage Battery Co., Washington, D. C.
Ratowsky, M., Bureau of Ships, Navy Dept., Washington, D. C.
Rau, A. W., Philadelphia Elec. Company, Philadelphia, Pa.
Reese, S. A., Philadelphia Elec. Co., Philadelphia, Pa.
Rhodes, A. W., Carbide & Carbon Chemicals Corp., South Charleston, W. Va.
Seifert, W. A., The Maryland Drydock Co., Baltimore, Md.
Sharp, R. F., Westinghouse Elec. Corp., E. Pittsburgh, Pa.
Sheridan, C. J., Triplett Elect. Instrument Co., Bluffton, Ohio
Shook, W. R., Jr., Elec. Machinery Mfg. Co., Cleveland, Ohio
Skorup, G. E., R.C.A. Victor Division, Camden, N. J.
Slaton, J. H., Dayton-Acme Co., Cincinnati, Ohio
Smith, D. L., Wright Field, Dayton, Ohio
Stradling, L. J., Jr., Allis-Chalmers Mfg. Co., Philadelphia, Pa.
Swing, H. P., Day & Zimmermann, Inc., Philadelphia, Pa.
Toffolo, D. S., Naval Research Laboratory, Anacostia, D. C.
Travis, C. E., N. Y. Ship. Corp., Camden, N. J.
Uremka, J. J., Reliance Elec. & Engg. Co., Cleveland, Ohio
Wheeler, W. P., Westinghouse Elec. Corp., E. Pittsburgh, Pa.
Wolf, A. J., Westinghouse Elec. Corp., E. Pittsburgh, Pa.
Wolfinger, C. P., Philadelphia Elec. Co., Philadelphia, Pa.

3. New York City

Brenner, M., 12 W. 183rd St., New York, N. Y.
Browne, W. A., N. Y. Port of Embarkation, Brooklyn, N. Y.
Chognard, J. C., 235 E. 73rd St., New York, N. Y.
Claypool, C., Otis Elevator Co., New York, N. Y.
Hattendorf, F. W., Jr., Gibbs & Cox, Inc., New York, N. Y.
Hillman, P. L., Press Wireless Mfg. Inc., Long Island City, N. Y.
Hughes, F. J., 2304 Sedgwick Avenue, N. Y., N. Y.
Ih, Y-H, Federal Telephone & Radio Corp., Newark, N. J.
Kopp, H. J., Public Service Elec. and Gas Company, Newark, N. J.
Karaus, F. J., Consolidated Edison Co. of N. Y., Inc., New York, N. Y.
Klinke, H. O., Air Reduction Co., Jersey City, N. J.
Lake, J. B., Jr., Westinghouse Elec. Intl. Co., New York, N. Y.
Long, F. V., Westinghouse Elec. Intl. Co., New York, N. Y.
Losowick, J. H., Western Elec. Co., Kearny, N. J.
Mayo, S. E., Jr., Federal Telephone & Radio Corp., Newark, N. J.
Mroz, J. E., Federal Tel. & Radio Corp., New York, N. Y.
Ostberg, O. S., U. S. Army, APO, New York, N. Y.
Pratt, I. P., Jr., USS *Corregidor*, FPO, New York, N. Y.
Shmoys, J., Sperry Gyroscope Co., Garden City, L. I., N. Y.
Stanley, W. G., Federal Tel. & Radio Co., Newark, N. J.
Upor, W. B., Gibbs & Cox, Inc., New York, N. Y.
Vail, T. F. X., Federal Telephone & Radio Corp., Newark, N. J.
Walsh, J. M., 2035 Chatterton Avenue, New York, N. Y.
Wong, H., 1019 Longwood Ave., Bronx, N. Y.
Yockel, A. P., Mackay Radio and Telegraph Co., New York, N. Y.

4. Southern

Birdsong, T. S., Alabama Power Co., Birmingham, Ala.
Black, A. F., Jr., Virginia Elec. & Power Co., Richmond, Va.
Brownell, H. S. (re-election), Birmingham Electric Co., Birmingham, Ala.
Cross, F., Tennessee Eastman Corp., Oak Ridge, Tenn.
Greer, R. C., Tennessee Valley Authority, Memphis, Tenn.
Jager, C. R., Alabama Power Co., Birmingham, Ala.
Hasinger, W. H., Jr., Alabama Power Co., Birmingham, Ala.
Johnston, J. A., Tri-County Elec. Cooperative, Inc., Lexington, Va.
Killingsworth, H. M., Birmingham Elec. Co., Birmingham, Ala.
Long, O., Southern Bell Telephone & Telegraph Co., Birmingham, Ala.
Martin, L., Carbide & Carbon Chem. Corp., Oak Ridge, Tenn.
Moseley, S. T., General Elec. Co., Roanoke, Va.
Murray, R. L., Alabama Power Co., Birmingham, Ala.
Olschner, P. Q., 437 Fern Street, New Orleans, La.
Rudolph, O. B., Tennessee Eastman Corp., Oak Ridge, Tenn.
Smith, H. R., Alabama Power Company, Birmingham, Ala.
Starr, M. S., Line Material Co., Birmingham, Ala.
Wilder, D. E., Jr., St. Petersburg Peninsular Tel. Co., St. Petersburg, Fla.

5. Great Lakes

Anderson, J. G., University of Minnesota, Minneapolis, Minn.
Blomeyer, E. C., Automatic Elec. Co., Chicago, Ill.
Boser, F., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Cadorette, R. J., Electric Service Engineering Co., Chicago, Ill.
Cofer, T. N., Central Ill. Public Service Co., Springfield, Ill.
Czerny, J. P., Jr., A-C Spark Plug Div., GMC, Flint, Mich.
Danford, W. R., Jr., Indiana Service Corp., Fort Wayne, Ind.
Dilay, W., General Electric X-Ray Corp., Detroit, Mich.
Enoch, F. W., Jr., Monsanto Chemical Co., Monsanto, Ill.
Ertan, C., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Fegley, V. S., Resistance Welder Corp., Bay City, Mich.
Gilbert, W. F., Michigan College of Mining & Technology, Houghton, Mich.
Grunwald, R., Illinois Bell Telephone Co., Chicago, Ill.
Hansen, J. D., Offner Electronics Co., Chicago, Ill.
Hodadon, A. E., Jr., Capt., U.S.A., Fort Snelling, Minn.
James, K. D., Harnischfeger Corp., Milwaukee, Wis.
Johnson, T. W., A-C Spark Plug Div., GMC, Flint, Mich.
Kantner, J. M., Consumers Power Co., Jackson, Mich.
Kintner, G. W., Kingan & Co., Indianapolis, Ind.
Kirchner, R. B. (Re-election), General Motors Corp., Fisher Body Div., Detroit, Mich.
Knopf, W. C., Jr., Northwestern Univ., Evanston, Ill.
Levin, H. H., Automatic Elec. Co., Chicago, Ill.
Marhoun, O. W., Northern States Power Co., St. Paul, Minn.
McKillop, I. A., Commonwealth Edison Co., Chicago, Ill.
Mitchell, D. N., Wilson Laboratories, Chicago, Ill.
Morgan, T. O., Buick Motor Div., GMC, Flint, Mich.
Nelson, L. E., Hubbard & Co., Chicago, Ill.
Randall, D. T., 821 E. Johnson St., Madison, Wis.
Robertson, W. R. A., Sibley, Iowa
Rowe, D. M., Murray Corporation of America, Detroit, Mich.
Vizard, W. F., Cover Dual Signal, Chicago, Ill.
Vogen, L. M., Commonwealth Edison Co., Chicago, Ill.
Weber, J. P., Jr., Thordarson Elec. Mfg. Div., Chicago, Ill.
Welker, C., Barber-Colman Co., Rockford, Ill.
Weyand, R. F., Western Union Teleg. Co., Chicago, Ill.

6. North Central

Fujimura, Y. J., 2415 Champa Street, Denver, Colo.
Greiner, J. A., Consumers Public Power District, Lincoln, Nebr.

7. South West

Cardwell, T. A., Jr., U. S. Engineers, Little Rock, Ark.
Caterson, H. L., Washington University, St. Louis, Mo.
Felling, W. E., U. S. Navy, Conway & Mason Rds., Clayton, Mo.
Gardner, K. G., General Elec. Co., Dallas, Tex.
Geery, P. W., Todd Houston Shipbuilding Corp., Houston, Tex.
Harnsfield, J. L., Houston Light and Power Company, Houston, Tex.
Johnston, A. B., Oklahoma Gas and Elec. Co., Ardmore, Okla.
Lewis, T. B., U. S. Engineer Office, Little Rock, Ark.
Moore, J. D., Humble Oil & Refining Co., Houston, Tex.
St. Pierre, W. W., Westinghouse Elec. Corp., St. Louis, Mo.
Shuffler, B. B., Freese & Nichols, Fort Worth, Tex.

8. Pacific

Anderson, R. W., Henger-Seltzer Co., Los Angeles, Calif.
Brannan, G. M., Southern Utility & Supply Co., Ajo, Ariz.
Burbeck, D. W., General Electric Co., Los Angeles, Calif.
Burchell, H. J. (Mis), General Elec. Co., Los Angeles, Calif.
Cottrell, B. P., Western Elec. Company, Phoenix, Ariz.
Delabar, V. J., U. S. Navy, San Francisco, Calif.
Dururum, A., P. O. Box 1075, Palo Alto, Calif.
Frey, F. V., Municipal Lt. & Pr. Dept., City Hall, Pasadena, Calif.
Gerlach, A. A., Signal Corps, U. S. Army, Fresno, Calif.
Hamilton, A. E., Dept. of Water & Power, Boulder City, Nev.
Holland, C. H., General Elec. Co., Los Angeles, Calif.
Hook, W. M., Western Union Telegraph Co., Oakland, Calif.
Jones, L. R., Jr., Ensign, USNR, FPO, San Francisco, Calif.
Kenline, G. B., San Diego Gas & Elec., San Diego, Calif.
Montgomery, W. L., Office of Supervisor of Shipbuilding, USN, San Francisco, Calif.
Mulborn, A. W., Pacific Gas & Elec. Co., San Francisco, Calif.
Nafius, D. E., C. F. Braun & Co., Alhambra, Calif.
Osborn, F. C., Jr., USS *Higbee*, FPO, San Francisco, Calif.
Paul, W. H., Lt., Signal Corps, APO, San Francisco, Calif.
Reber, E. A., General Elec. Co., San Francisco, Calif.
Ross, N. C., Dow Chemical Co., Pittsburg, Calif.
Sakelaris, G. J., Ensign, USNR, USS *Rutland*, FPO, San Francisco, Calif.
Sterrett, D. H., USS *Wisconsin*, FPO, San Francisco, Calif.
Sweetland, R. N., LOON Test Group, AATD, Port Hueneme, Calif.

9. North West

Dunkle, S. L., % Communications Engineering, Hillfield, Utah
Johnson, H. E., Lt., USNR, Office of Port Director, Seattle, Wash.
Widrig, T. M., Trumbull Elec. Manufacturing Company, Seattle, Wash.

10. Canada

Adamson, D. M., RCNVR, Darthmouth, N. S., Can.
Ball, W. B., University of Toronto, Toronto, Ont., Can.
Bath, D. T., University of Alberta, Edmonton, Alberta, Can.
Best, G. C., Turbo Research, Ltd., Leaside, Ont., Can.
Calderone, A. C., A. V. Roe Canada Ltd., Malton, Ont., Can.
China, N. W., Dominion Rubber Co., Ltd., Montreal, Que., Can.
Cormick, H. L., University of Alberta, Edmonton, Alberta, Can.
Elliott, R. E., Amalgamated Elec. Corp., Toronto, Ont., Can.
Goudge, A. R., Canadian General Elec., Peterboro, Ont., Can.
Grosskurth, R. A., The Bell Telephone Co. of Canada, Toronto, Ont., Can.
Gusen, A., Hydro-Elec. Power Comm. of Ont., Toronto, Ont., Can.
Healey, A. J., Canadian Westinghouse Co., Ltd., Hamilton, Ont., Can.
Hicks, R. L., Canadian General Elec. Co., Toronto, Ont., Can.
Kravets, A. J., National Research Council, Ottawa, Ont., Can.
Lam, M., National Research Council of Can., Ottawa, Can.
LeBus, G. H., Canadian Westinghouse Co. Ltd., Hamilton, Ont., Can.
Lytle, D. D., Canadian Westinghouse Co. Ltd., Hamilton, Ont., Can.
Newbury, E. W., Canadian Westinghouse Co. Ltd., Hamilton, Ont., Can.
Quentin, A. F., Canadian National Carbon Co., Ltd., Toronto, Ontario, Can.
Shillen, J. F., Canadian Westinghouse Co., Ltd., Hamilton, Ont., Can.
Slader, G. Y., McGill University, Montreal, Que., Can.
Smith, A. W., Automatic Elec. (Canada), Limited, Toronto, Can.
Stevinson, A. L., Canadian General Elec., Peterboro, Ont., Can.
Stothert, W. D., Dept. of Public Works, Calgary, Alberta, Can.
Taylor, R., Canadian Standards Assn., Toronto, Ont., Can.
Walker, W. M., British Columbia Elec. Railway Co., Vancouver, B. C., Can.
Wilmot, R. D., National Research Council, Ottawa, Ont., Can.
Winch, E. M. P., English Electric Co. of Canada, Ltd., Vancouver, B. C., Can.

Elsewhere

Barker, C. G., United River Plate Telephone Co., Buenos Aires, S. A.
Cabrera, F. H., The Mexican Light & Power Co., Ltd., Mexico, D. F., Mexico
del Campo y Gutierrez, A. M., Mexican Light and Power Co., Mexico D. F., Mexico
El Ansary, H., Electricity & Water Works, Mchalla, El-Kobra, Egypt
Gil, F., The Mexican Light and Power Co., Mexico D. F., Mexico
Giron, L. S., Mexican Light and Power Co., Mexico D. F., Mexico
Gronner, A., 2400 Durazno, Montevideo R. O. del Uruguay, S. A.
Meijling, J. (re-relection), Kooperativa Forbundet, Stockholm, Sweden
Ovalle, E., Empresa Nacional de Electricidad S. A., Santiago, Chile, S. A.
Palomo y F., O. R., Compania Colombiana de Electricidad, Barranquilla, Rep. de Colombia, S. A.
Rao, B. S., C.N.T. Institute, Vepery, Madras, India
Thoraresen, R., Icelandic State Electricity Control, Reykjavik, Iceland

Total to grade of Associate

United States and Canada, 232

Elsewhere, 12

OF CURRENT INTEREST

Eta Kappa Nu Honors Karapetoff

A dinner meeting in honor of Vladimir Karapetoff (F '12) emeritus professor of electrical engineering, Cornell University, Ithaca, N. Y., was held by Eta Kappa Nu, honorary electrical engineering fraternity in New York, N. Y., on January 21, 1946, on the occasion of his 70th birthday.

Professor Karapetoff, who incurred blindness in 1943, described the nature of the affliction and measures taken to overcome it in order to lend encouragement to others who may be afflicted similarly, particularly as a result of war injuries. He described how the first sign of impending trouble was a detached retina in one eye in May 1942 followed by the same impairment in the other eye in the following year, with subsequent complication by cataracts. Recent operations have brought a very limited ability to distinguish objects. However, by learning to read Braille including music, by writing with a typewriter using a continuous roll of paper, by the use of a Braille typewriter for preparing memoranda, and by the use of "talking books" or phonograph records prepared especially for the blind, he states that he is able to engage in activities limited only by time available.

Speaking on the subject "Dynamics of National Conflicts," Professor Karapetoff pointed out that the behavior of people and nations follows a pattern determined by natural laws and cannot be controlled by establishing a pattern of ideals no matter how desirable these may be. He likened the need for judicial powers in the United Nations Organization to that existing in other governments which are required to perform administrative, legislative, and judicial functions.

The meeting was sponsored by the New York alumni chapter of Eta Kappa Nu, which presented Professor Karapetoff with a record player and a set of records.

Construction Opportunities Booklet. The Committee on Opportunities for Veterans in the Construction Industry, an industry-wide committee upon which the AIEE is represented, announces publication of a booklet entitled "Opportunity Unlimited—A Guide for Veterans Interested in the Construction Industry." Addressed specifically to veterans, the booklet hopes to attract capable men to the industry on a long-range basis. It discusses the professions, skilled trades, apprentice training, and business opportunities. A number of copies are available at Institute headquarters and may be obtained by writing to the American Institute of Electrical Engineers, 33 West 39th Street, New York 18, N. Y.

Billion-Volt X Rays Produced

A new atom-smashing machine to which the name "sigmatron" has been applied was described recently by Doctor E. E. Charlton of the General Electric Company. In it an electron will be subjected to two processes of acceleration, first in a cyclotron and then in a betatron. The physical dimensions of the cyclotron and betatron are such that the former may be placed inside the latter to form the combined machine, which is said to produce billion-volt X rays.

Announcement of the artificial production of mesons, one of the chief constituents of cosmic rays, was made at a meeting of the American Physical Society in papers by Doctor G. C. Baldwin, A. J. Hartzler, and Doctor G. S. Klaiber, all of the General Electric Research Laboratory, and Doctor Marcel Schein of the University of Chicago. The meson is a particle considerably more massive than the electron, though lighter than the proton, and is produced in the atmosphere high above the earth's surface by cosmic radiation from outer space, lasting but a few millionths of a second on the average. Photographic evidence shows the production of mesons, as well as protons, electrons, positrons, and other particles, in the 100,000,000-volt betatron.

Long-Range Direction Finders. Long-range high-frequency direction finders which were able to locate underseas craft operating half way across the ocean were employed by the United States Navy during World War II. This fact was disclosed for the first time at a recent demonstration of the devices staged jointly by the United States Navy and the Federal Telephone and Radio Corporation, Newark, N. J., at the company's Great River, N. Y., experimental station. As the new direction finder relied upon the use of its radio by the enemy submarine to reveal its location, it was necessary to keep the development one of the most carefully guarded secrets of the war.

Engineering Vacancies. With a staff requirement of 3,200 to be met by July 1 of this year, the United States Department of the Interior Bureau of Reclamation, Denver, Colo., has vacancies for 2,250 engineers at salaries ranging from $2,320 to $5,180 per year, or engineering aides to be paid from $1,572 to $2,980 per year. Applicants will be judged on the basis of experience and training and will not be required to take written examinations although veterans are given preference in civil service appointments. Inquiries should be sent to the Bureau of Reclamation, Room 457, New Customhouse, Denver 2, Colo.

A Reading List for Electrical Engineers

The following well-chosen list of books of interest to electrical engineers has been compiled by the staff of the Engineering Societies Library. This selection was made from the collection added to the library during 1945. Some equally good books may have been omitted from the list but the desire of the compilers was for brevity rather than all-inclusiveness.

ENGINEERING CONTRACTS AND SPECIFICATIONS. By R. W. Abbott. John Wiley and Sons, Inc., New York, N. Y. 188 pages, $2.25. Some of the legal and business aspects of the engineering profession are presented in convenient reference form. This is written for practical engineers and contractors as well as college students.

NETWORK ANALYSIS AND FEEDBACK AMPLIFIER DESIGN. By H. W. Bode. D. Van Nostrand Company, Inc., New York, N. Y. 551 pages, $7.50. This is a treatise on general network theory with material on the design of nonfeedback as well as feedback amplifiers, particularly those of wideband type, and on miscellaneous transmission problems arising in wideband systems.

SIMPLE CALCULATION OF ELECTRICAL TRANSIENTS; AN ELEMENTARY TREATMENT OF TRANSIENT PROBLEMS IN LINEAR ELECTRICAL CIRCUITS. By G. W. Carter. Macmillan Company, New York, N. Y. 120 pages, $1.75. These calculations are based on Heaviside's operational method in linear electrical circuits with lumped elements. Engineering aspects are emphasized.

ELECTRONICS DICTIONARY. By N. M. Cooke and J. Markus. McGraw-Hill Book Company, Inc., New York, N. Y. 433 pages, $5. An illustrated glossary of more than 6,000 terms used in radio, television, industrial electronics, communications, facsimile and sound recording.

POWER SYSTEM STABILITY. Volume I, Steady State Stability. By S. B. Crary. John Wiley and Sons, Inc., New York, N. Y. 291 pages, $4. Presents the fundamental theory underlying maintenance of continuous electric power under normal and abnormal operating conditions. Discusses applications of the theory of steady state stability. Volume II: Transient Stability (in preparation).

TRANSMISSION LINES. By F. C. DeWeese. McGraw-Hill Book Company, Inc., New York, N. Y. 297 pages, $3.50. This comprehensive work deals exclusively with the design, construction, and performance of lines for the transmission of electric power. Material is presented so as to be useful to beginners and advanced students.

ELECTRICAL COILS AND CONDUCTORS; THEIR ELECTRICAL CHARACTERISTICS AND THEORY. By H. B. Dwight. McGraw-Hill Book Company, Inc., New York, N. Y. 351 pages, $5. Most of the calculations presuppose a knowledge of the principles of the operation of electric apparatus and a working knowledge of integral calculus.

BASIC ELECTRICAL ENGINEERING; CIRCUITS, MACHINES, AND ELECTRONICS. By A. E. Fitzgerald. McGraw-Hill Book Company, Inc., New York, N. Y. 443 pages, $3.75. This is an elementary exposition of the electric-circuit theory requisite in the foundation of all electrical engineering students.

MECHANICAL AND ELECTRICAL EQUIPMENT FOR BUILDINGS. Second Edition. By C. M. Gay and C. de van Fawcett. John Wiley and Sons, Inc., New York, N. Y. 453 pages, $5. Covers basic theories and applications concerned with building equipment, including water supply, plumbing and

drainage, heating and air conditioning, electric equipment, and acoustics.

ELECTROLYTIC CAPACITOR. By A. M. Georgiev. Murray Hill Books, Inc., New York, N. Y. 191 pages, $3. Describes the construction, manufacture, function, and testing of dry and wet electrolytic capacitors, explains the operating characteristics of the various types, and indicates their useful applications and limitations.

ENGINEERING PREVIEW; AN INTRODUCTION TO ENGINEERING INCLUDING THE NECESSARY REVIEW OF SCIENCE AND MATHEMATICS. By L. E. Grinter. Macmillan Company, New York, N. Y. 581 pages, $4.50. Treats the background science of engineering—mathematics, chemistry, physics, and technical drawing—to enable the reader to orient himself and determine whether engineering is the field he should choose.

CONTROLLERS FOR ELECTRIC MOTORS; A TREATISE ON THE MODERN INDUSTRIAL CONTROLLER WITH TYPICAL APPLICATIONS TO THE INDUSTRIES. By H. D. James and others. McGraw-Hill Book Company, Inc., New York, N. Y. 324 pages, $3.50. Describes the construction, performance, and operation of various types of commercial motor controls in general use. Protective devices are explained in detail, and a brief set of instructions for the installation and maintenance of the devices is included.

ELECTROMAGNETIC ENGINEERING. Volume I, Fundamentals. By R. W. P. King. McGraw-Hill Book Company, Inc., New York, N. Y. 580 pages, $6. This textbook is based on a war-training course. It avoids the use of higher mathematics.

TRANSMISSION LINES, ANTENNAS, AND WAVE GUIDES. By R. W. P. King, H. P. Minno, and A. H. Wing. McGraw-Hill Book Company, Inc., New York, N. Y. 347 pages, $3.50. The physical and mathematical background prerequisite to the systematic study of antennas, wave propagation, transmission circuits, including wave guides and microwave generators, is presented in this, the first of a proposed series of three volumes.

UHF RADIO SIMPLIFIED. By M. S. Kiver. D. Van Nostrand Company, New York, N. Y. 238 pages, $3.25. The concepts of ultrahigh-frequency radio are presented as logical outgrowths of the more familiar low-frequency equipment. Describes the important pieces of equipment: magnetron, oscillators, wave guides, cavity resonators, antennas, measuring instruments. Explains principles of reduction, transmission, and measuring of ultrahigh-frequency currents and waves.

MARINE ELECTRIC POWER. By Q. B. Newman. Simmons-Boardman Publishing Corporation, New York, N. Y. 244 pages, $2.50. This is an elementary textbook covering electrical theory, principles of electrical engineering, and use of electric equipment on ships.

INDUSTRIAL ELECTRIC FURNACES AND APPLIANCES. Volume I. By V. Paschkis. Interscience Publishers, Inc., New York, N. Y. 232 pages, $4.90. Covers thermal, electric, and economic principles applying to all types of furnaces and appliances. Discusses arc furnaces and electrode-melting furnaces, with special attention to ferro-alloy furnaces. Emphasis is placed on the thermal aspects of furnace design and operation. A second volume will cover induction, capacitance, and resistance heating.

ELECTRONIC ENGINEERING MASTER INDEX, A SUBJECT INDEX TO ELECTRONIC ENGINEERING PERIODICALS. Edited by F. A. Petraglia. Electronic Research Publishing Company, New York, N. Y. 318 pages, $17.50. Contains approximately 15,000 entries nearly all of which refer to material published in English language technical magazines and society publications. No abstracts or annotations are included.

INTRODUCTION TO MICROWAVES. By S. Ramo. McGraw-Hill Book Company, Inc., New York, N. Y. 138 pages, $1.75. This is an elementary non-mathematical discussion of microwaves.

New Electronic Calculator

Officials who were responsible for the development of the "electronic numerical integrator and computor" designed and constructed by the Moore School of Electrical Engineering, University of Pennsylvania, Philadelphia, for the United States Army Ordnance Department are shown at its dedication. Containing nearly 18,000 vacuum tubes in its mechanism, the new calculator occupies a room 30 by 50 feet and weighs 30 tons. It is said to be the first all-electronic general purpose calculator and to compute 1,000 times faster than any similar machine previously built. Originally developed for the computation of firing and bombing tables for vital ordnance equipment, the device can find many peacetime applications in such fields as nuclear physics, aerodynamics, and scientific weather predictions. Left to right are J. P. Eckert, Jr., Moore School; Professor J. G. Brainerd (M '39) Moore School, and chairman of the AIEE committee on basic sciences; Sam Feltman, chief engineer for ballistics, United States Army Ordnance Department; Captain H. H. Goldstine, liaison officer; Doctor J. W. Mauchly, Moore School; Doctor Harold Pender (F '14) dean, Moore School; General G. M. Barnes, chief of the United States Army Ordnance Research and Development Service; and Colonel P. N. Gillon, chief of the research branch, United States Army Ordnance Research and Development Service

Message to Moon Proves Atmosphere Penetration

The principal significance of the radar-to-the-moon tests recently conducted by the United States Army Signal Corps, according to Major General Harry C. Ingles, Chief Signal Officer of the Army, is that they demonstrated for the first time that radio waves in the very high frequency band will penetrate completely the ionosphere, the celestial void, and whatever form of atmosphere that may surround the moon. Although the waves had to travel 238,000 miles to the moon the penetration was accomplished without distortion or refraction.

The radar set employed in the tests at the Evans Signal Laboratory, Belmar, N. J., was designed primarily for long-range detection of hostile aircraft but for transmission over so great a distance it was necessary to modify the oscillators and to add a second complete antenna unit. The

set was operated on its standard frequency of 111 megacycles, a wave length of 300 centimeters, which lies in the very high frequency range.

REA Adds Electro-Agricultural Section. A new section of the Rural Electrification Administration's Technical Standards Division has been established to organize, promote, and co-ordinate programs in the development of new electro-agricultural equipment and the improvement of existing devices of benefit to the farmer according to an announcement made by Claude R. Wickard, administrator. The electro-agriculture section, as it will be known, will be concerned with the development of new electric equipment designed to meet farm needs and will work with colleges and other groups carrying on research programs. The information will be made available to manufacturers for commercial development and quantity production at lower costs. REA borrowers will be given information concerning new developments in electric equipment which will improve living conditions and increase farm profits.

INDUSTRY

Gwilym A. Price
Westinghouse President

Gwilym A. Price, vice-president and member of the board of directors, has been elected president of the Westinghouse Electric Corporation, East Pittsburgh, Pa., to succeed George H. Bucher, who has resigned. Under a recent amendment of the corporation's bylaws, Mr. Price as president will be chief executive officer.

Mr. Price at the age of 50 is one of the United States' youngest directors of a large corporation. He was born in Canonsburg, Pa., in 1895 and is a graduate of the University of Pittsburgh Law School (1917). Prior to his election as an officer of the Westinghouse corporation in 1943, Mr. Price had been president of the Peoples-Pittsburgh Trust Company of Pittsburgh, Pa., an organization with which he had been associated since 1923.

Mr. Bucher will continue with the company as vice-chairman of the board of directors and as chairman of the Westinghouse Electric International Company.

Lighting Survey. A minimum of four million new luminaires or lighting fixtures for approximately 50,000 miles of automotive throughfare and 250,000 miles of residential streets at an estimated installed cost of 500 million dollars will be needed for new and replacement traffic safety lighting in the United States during the next ten years according to a recently completed survey of the country's lighting conditions made by Doctor A. F. Dickerson, manager of the lighting division, General Electric Company, Schenectady, N. Y. The survey emphasized the fact that improper illumination can be credited as the chief cause of increasing automobile accidents which claimed, during the period from December 7, 1941, to June 1, 1945, three casualties for every American war casualty.

Wire Stripping Method. After a year of production and demonstration, a method for removing insulation from fine electrical wires, developed by the Fairchild Camera and Instrument Corporation, Jamaica, N. Y., is said to have exceeded original expectations. Initially intended for application to wires covered with certain synthetics, it has enabled electrical manufacturers to strip all modern types of synthetic covered wires with no change in wire size or physical properties. In this method the ends of fine wire to be stripped first are dipped quickly in one chemical solution, then immediately in a final solution which acts as an accelerator, and then gently stroked to remove the insulation. The process is patented by the corporation which is licensing electrical manufacturers to use it.

Gas Turbine Progress. Successful operation at a gas temperature of 1,350 degrees Fahrenheit has been accomplished in tests on a gas turbine plant installed in the United States Naval Engineering Experiment Station, Annapolis, Md., it was announced recently. The 3,500-horsepower unit was designed by the Allis-Chalmers Manufacturing Company, Milwaukee, Wis., for eventual operation with hot gas at a temperature of 1,500 degrees Fahrenheit. It embodies cooling methods which permit the multistage turbines to operate safely at high inlet temperature by avoiding the undue weakening effect of the high temperature on the materials used for the rotating parts.

New Generating Station. Construction of a new generating station on the Arthur Kill at Sewaren, Woodbridge, N. J., is planned by the Public Service Electric and Gas Company for the autumn of 1946. The initial step in the project includes the installation of two 100,000-kw high-pressure high-efficiency generating units, with the necessary auxiliary apparatus, buildings, docks, electrical switching and transformer equipment, and connecting transmission lines, estimated to cost 23 million dollars.

Elastic Plastic. A new elastic plastic, "Marvinol" resin, has been developed by The Glenn L. Martin Company, Baltimore, Md., according to a recent announcement. The raw material will be manufactured by a new plant to be operated by the plastics and chemicals divisions of the company and will be sold only to converters and fabricators. Mixed with other substances, these polyvinyl resins can be used for a large variety of commercial products including multicolored wire insulation, woven fabrics, and industrial gloves.

"Electrical Living." Jobs for 600,000 persons and an annual business of more than four billion dollars for the next five years were forecast by B. W. Clark, vice-president in charge of sales of Westinghouse Electric Corporation, as a result of expanded application of electricity in homes. Speaking at a preview of new home products, Mr. Clark emphasized the need for adequate wiring in homes, and estimated that $150,000,000 per year for several years should be expended in rewiring existing homes. A color cartoon film produced by Walt Disney Studios has been made available to help inform the public of this need.

Newcomer in F-M Field. According to a recent announcement of the Federal Telephone and Radio Corporation, Newark, N. J., the company currently is building frequency modulated broadcast transmitting equipment for 170 installations, its initial venture into that field. The equipment will incorporate a new type of modulator-oscillator unit which is claimed to make possible a very low noise reception level.

Movie Presents Transportation Problem. An all-color sound motion picture, "Lifestream of the City," produced to illustrate the advantages of a well-planned efficient public transit system, has been made available by the General Electric Company, Schenectady, N. Y., to civic and business organizations, schools, colleges, and transit and power companies. The film attempts to prove that modern public transit vehicles, by using existing street space more efficiently, will solve the traffic congestion problem caused by the increasing use of private automobiles. Information about the film, which can be used on sound-equipped 16-millimeter projectors only, may be obtained from the company's visual instruction section, Schenectady, N. Y., or by inquiry at any local office.

"Standardized" Steam Turbines. In accordance with "Preferred Standards for Large 3,600-Rpm Three-Phase 60-Cycle Condensing Steam Turbine Generators" prepared by the joint committee on steam turbine generators of the AIEE and the American Society of Mechanical Engineers (*EE, May '45, p 180*), the first "standardized" steam turbine built for electric power generation is in production at the South Philadelphia, Pa., plant of the Westinghouse Electric Corporation, L. E. Osborne, vice-president, announced recently. The unit, a 30,000-kw machine, initiates a program of standardization which, it is expected, not only will speed up production but will facilitate repairs and servicing.

Hermetically Sealed Rectifier. A selenium rectifier which can be submerged in boiling water or packed in ice and still function at an efficiency equal to that obtained under normal operating conditions has been announced by the Westinghouse Electric Corporation, East Pittsburgh, Pa. The rectifier was designed for wartime use to withstand the extreme temperatures experienced on the various battlefronts. It is said also to resist salt spray, insects, fungi, and humidity.

RESEARCH

Aeronautical Laboratory for Cornell. The combined gifts to Cornell University, Ithaca, N. Y., of the Curtiss-Wright Corporation's airplane division research laboratory, Buffalo, N. Y., and $675,000 in working capital from seven aircraft companies provide the university with a laboratory in which industrial research can be carried on simultaneously with the professional training of aeronautical engineering students according to Doctor C. C. Furnas, the laboratory's director. The staff of instruction will be selected both from the laboratory and from the college of engineering at the university and students will divide their time between the Ithaca campus and Buffalo.

MIT Acoustics Laboratory. Establishment of an acoustics laboratory, a new interdepartmental facility in a branch of science which produced important developments during World War II, was announced recently by Doctor Karl T. Compton (F '31) president, Massachusetts Institute of Technology, Cambridge. One of the primary objectives of the new laboratory is to provide fundamental professional training in a field in which there is now a serious shortage of competent engineers and scientists. It is to be operated under the joint direction of the institute's departments of electrical engineering and physics and the school of architecture and planning with Doctor Richard H. Bolt as director.

OTHER SOCIETIES

Award Fund. The American Association for the Advancement of Science, Washington, D. C., has announced the establishment of the George Westinghouse Science Writing Award Fund to give recognition to newspaper writers and newspapers contributing most to effect a better popular understanding of the achievements of science and technology. The fund, which will be administered by the association, is supported by the Westinghouse Electric Corporation in commemoration of the 100th anniversary of the birth of George Westinghouse. In addition to the cash award and the citation, special citations in recognition to distinguished service in science journalism may be awarded. The first annual awards, for the year 1946, will be made at the winter meeting of the association in December 1946.

Ophthalmology Publication. "Industrial Aspects of Ophthalmology," proceedings of a 1944 seminar conducted by the National Society for the Prevention of Blindness, 1790 Broadway, New York 19, N. Y., is now available from that society. The price is one dollar. The contents of the 150-page publication include "Survey of Eye Conditions in Industry," "Industrial First Aid—Eye Injuries," and "Improving the Visibility of Industrial Tasks."

Welding Inspection Handbook. The "Inspection Handbook for Manual Metal Arc Welding" published by the American Welding Society now is available. It covers the requirements and duties of a welding inspector, methods of testing welds, and contains a description of weld inspection by visual, magnetic-particle, and radiographic methods. Copies may be obtained from the American Welding Society, 33 West 39th Street, New York 18, N. Y., at $1.50 each.

Future Meetings of Other Societies

American Association for the Advancement of Science. March 27–29, 1946, St. Louis, Mo.

American Chemical Society. National Chemical Exposition. September 10–14, 1946, Chicago, Ill.

American Society for Testing Materials. Forty-ninth annual meeting. June 24–28, 1946, Buffalo, N. Y.

American Society of Mechanical Engineers. Spring meeting. April 1–3, 1946, Chattanooga, Tenn.

American Society of Tool Engineers. Exposition. April 8–12, 1946, Cleveland, Ohio.

Electrochemical Society. Spring meeting. April 10–13, 1946, Birmingham, Ala.

Great Lakes Power Club. Spring meeting. May 24, 1946, Chicago, Ill.

Illuminating Engineering Society. National convention. September 18–21, 1946, Quebec, Quebec, Canada.

Instrument Society of America. Exhibit and conference. September 16–20, 1946, Pittsburgh, Pa.

Midwest Power Conference. Annual meeting. April 3–5, 1946, Chicago, Ill.

National Association of Corrosion Engineers. Annual meeting and convention. May 7–9, 1946, Kansas City, Mo.

National Electrical Manufacturers Association. First International Lighting Exposition. April 25–30, 1946, Chicago, Ill.

Pennsylvania Electric Association. Spring meeting. May 28–29, 1946, Harrisburg, Pa.

Radio Manufacturers Association. Trade show. May 13–16, 1946. Chicago, Ill.

Society of Plastics Industry. First national plastics exposition. April 22–27, 1946, New York, N. Y.

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinions dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

Behavior of a Freely Pivoted Disk

To the Editor:

As the gyrostat long since has come within the ambit of the electrical engineer's professional interests, a letter on the subject seems not out of place. Does not the fascination of the running gyrostat's behavior cause us to overlook some quite remarkable characteristics of the stationary pivoted disk, characteristics which on the one hand illustrate second-order torque terms of the running gyrostat; and on the other hand, in spite of the minuteness of these terms, are susceptible of the easiest possible practical demonstration. Not only are these of immediate interest as unexpected effects, but an appreciation of them fortifies our subconscious critical faculty against erroneous though plausible arguments which have appeared[1] fairly recently under even the most distinguished authorship. For instance, we may need to define our meaning of angular velocity of the gyrostat's disk about its spin axis when that axis simultaneously is changing its inclination to the vertical and swinging about the vertical (precession), and we may be seduced by its simplicity to adopt for this definition the rate of change of angular interval between a marked radius on the disk and that particular radial line which is horizontal at the moment under consideration. This quantity ϕ certainly defines a real angular velocity, but we shall be begging the question if we tacitly assume that it is the actual angular velocity of spin such as would be ascertained by fundamental kinematical examination and which, as is known, remains constant in the absence of external torque about the spin axis. It is a well-known dynamical fact[2] that, for a disk pivoted on a principal axis passing through its center of mass and having the

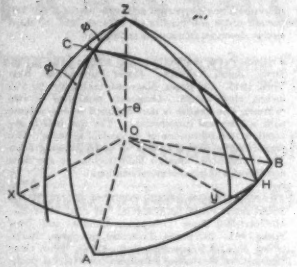

Figure 1. Diagram of Euler's moving axes *ABC* fixed in the gyrostat disk and related by the co-ordinates $\theta\phi\psi$ to the axes *XYZ* fixed in space

The line OH has been added at right angles both to OC the spin axis and to OZ the vertical, therefore representing that radius of the disk which is horizontal. HB thus becomes the angular interval between the horizontal radius and the marked one, and will be seen to be equal to Euler's ϕ

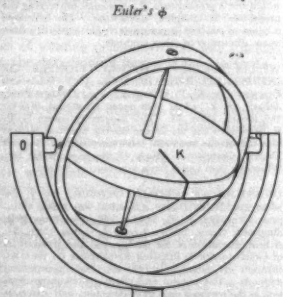

Figure 2. Demonstration-type gyrostat

other two principal moments of inertia equal the one to the other about axes through that center, the true angular velocity about the axis of pivoting—which we here call ω_1—is unaffected by any movement given to the spin axis, for instance via gimbal rings, and is subordinate only to external couple such as pivot friction and kindred. But this property of constancy does not pertain to ϕ; indeed ϕ will be found to correspond to one of the co-ordinates of the disk used in Euler's analytical method wherein moving rectangular axes fixed in the disk are referred by the co-ordinates $\theta\phi\psi$ to a similar set fixed in space, and the true velocity of spin ω_3 is given by $\phi+\dot{\psi}\cos\theta$ (see Figure 1).

In the case of the running gyrostat, the term $\dot{\psi}$ is so small compared with $\dot{\phi}$ that we could not expect to find any simple experimental differentiation between ω_3 and ϕ; but the known constancy of angular velocity is true irrespective of its numerical value, and therefore also when this value is zero. In those circumstances $\dot{\psi}$ becomes the major part of the quantity examined, hence the beauty of a test on the pivoted disk without spin. Let us then take an ordinary gyrostat as depicted in Figure 2 and clamp the trunnions so that the spin axis makes an angle of about 30 degrees with the vertical. Let the disk be at rest and free in its pivots and let a chalk mark K be made on the top surface of the disk along the lowest radius. Now let us turn the yoke upon its vertical pivot slowly enough for the effects to be watched. The chalk mark does not stay at the bottom, nor is pivot friction responsible for the movement relative to gimbal ring since it is in the reverse direction. By continuing the turning of the yoke the chalk mark may be brought to the top, and on around to the bottom again, and so on; yet it may be asserted confidently that ω_3, the velocity of the disk about its spin axis, has been zero all the time except to the extent that slight pivot friction has been at play and has caused turning of the disk in the direction opposite to that believed to have been observed. We thus shall have seen that since ϕ started with zero value, and subsequently assumed various values, it is not a quantity which can be used as a measure of spin velocity. We still are left with the apparent paradox of the test appearances on the one hand, and the knowledge that the disk cannot have turned upon its axis in the observed direction. The explanation is simple*; but it may suffice here merely to make the bold assertions that, in spite of the trunnion axis remaining horizontal all the time, it was that axis, and not the disk,

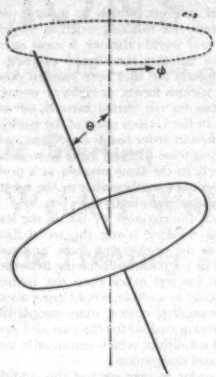

Figure 3. Simple diagram defining the co-ordinates $\theta\psi$

which turned about the spin axis causing a relative movement of chalk mark and trunnion axis, and the chalk mark moved from a low to a high position on the disk, and changed in its North–South azimuth, by tilting of the disk about a succession of diameters, and not by rotation of the disk on its spin axis.

Of other characteristic properties of the freely pivoted disk one only will be referred to, namely the simulation of negative centrifugal force, an effect again affording instant check upon analytical results. It arises in this way. Taking again the gyrostat of Figure 2 with the disk at rest, but this time with the trunnions free, let us give the yoke a slight spin in either direction about its vertical pivot and watch the behavior of the inner gimbal ring. It is clear that, were the disk jammed in its pivots, the inner ring would turn on its trunnions to bring the disk axis toward the vertical, this being the normal result of centrifugal force on elements of the disk. The actual result, with pivots free, is the reverse of this. Two questions present themselves here. May the pivot friction cause a sufficient spin of the disk for the resulting large gyrostatic effect to cause the observed turning toward the horizontal? The answer is that such spin as may be produced will cause a reverse tendency not a helping one. Can the centrifugal force upon the inner gimbal ring itself, which is certainly in the right direction, be responsible? The gimbal ring is usually relatively light, but this query only can be answered positively by countering the couple produced by the said centrifugal force. For his personal satisfaction the writer modified a two-ring torpedo gyrostat by attaching a structure to the inner ring whereby weights could be located suitably outside the outer gimbal to counter the couple of the centrifugal forces upon the inner one. The test result was unchanged. So much for qualitative demonstration. For quantitative verification recourse must be had to calculation, namely a determination of that part of the torque about the trunnion axis which is required to counter the inertia couple produced by the disk. The result for the case of jammed pivots is found easily by simple procedure. For the case of the freely pivoted disk we may choose to remain on unassailable ground using Euler's equations and co-ordinates and resolving the couples and then substituting in the final result zero value for the angular velocity of disk spin. The calculation however can be made quite soundly using these same co-ordinates (see Figure 3) and treating the components of angular momentum as vectors.[3] The results will be found to be

for the freely pivoted disk

$$A\ddot{\theta}-{}^1/_2A\dot{\psi}^2\sin 2\theta$$

for jammed pivots

$$A\ddot{\theta}+{}^1/_2(C-A)\dot{\psi}^2\sin 2\theta$$

where A, A, C, represent the three principal moments of inertia at the disk's centroid. If now the disk be reasonably thin for its diameter, the larger moment of inertia C will be substantially equal to $2A$ and there-

* The two assertions will be acceptable to the reader if he will consider the result on the ring and the disk of giving a small displacement $h\dot{\psi}$ to the yoke about its vertical axis, which is equivalent to $(-h\dot{\psi}\sin\theta)$ about a line momentarily coinciding with the lowest disk radius plus $(h\dot{\psi}\cos\theta)$ about the spin axis. He will note that the second component can have no effect upon the disk in the absence of pivot friction.

fore the said trunnion torque required to hold θ constant, with given values of θ and ψ, will be the same for the two conditions of pivots except only for sign. We thus have complete simulation of negative centrifugal force. We note that with free pivots, since ψ^2 is essentially positive, δ is necessarily of the same sign as $\sin 2\theta$ if the trunnions are free, an immediate check upon the sign of our second-order torque term for the running gyrostat.

REFERENCES

1. *Proceedings*, Institution of Mechanical Engineers, London, England, volume 151, pages 232-3.

2. **Dynamics of a System of Rigid Bodies, E. J. Routh.** Macmillan and Company Limited, 1891, volume 1, page 215.

3. **A Treatise on Gyrostatics and Rotational Motion, Andrew Gray.** Macmillan and Company Limited, 1918, pages 51-6.

4. **1915 Kelvin Lecture, Andrew Gray.** *Journal* Institution of Electrical Engineers, London, England, volume 53, pages 293-4.

A. B. FIELD (F '13)

(Consulting engineer, retired, Marple, Cheshire, England)

Liberal Education for Engineers

To the Editor:

The need of liberal education for engineers becomes more and more evident. Every new scientific discovery is hailed as a boon to mankind. However, advancement, if indeed any, toward producing more human happiness as a result of new scientific discoveries, has been very slow. History proves instead that all scientific discoveries are turned towards destructive rather than creative ends. This is, of course, not the scientist's purpose, but is due to a combination of lack of interest and wrong thinking on the part of the average individual including the scientist and engineer.

Engineers as men of science are men of logic and reason along those lines, and therefore, have a very good start toward becoming our most logical thinkers along social lines providing they avail themselves of the necessary information and thus have their interest aroused.

Due to economic conditions the engineer after leaving college devotes most of his time to the business of making a living. He, therefore, strives constantly to improve his technique in the engineering service rendered with a view toward greater remuneration and in doing this tends to lose sight of the importance he might play in the shaping of a better world, in which his labors would be turned toward maximum usefulness for humanity.

In order to improve the afore-mentioned condition and make the engineer more social-minded and thus a better world citizen, it seems that much greater emphasis must be placed on liberal education in our engineering colleges. Languages, literature, and philosophy are essential, and an objective study of the most controversial subjects, which to a large degree influence our thinking, such as world history, and world religions, is most essential.

The last two mentioned subjects have throughout the ages been handed down in their various forms, as right or wrong, depending on the vested interest advancing them in the various parts of the world, and therefore in order to advance clear and free thinking these subjects must be studied objectively in the same manner as a problem in physics or mathematics or the subject of mythology is studied.

Thus the engineer by taking the lead in logical thinking along the social lines as well as the engineering lines, and usually being in the position of having little specific vested interest other than the welfare of humanity as a whole, would bring about an understanding among more people of the underlying reasons for the past and present world conditions which continually lead to wars and destruction.

In order to take care of this additional liberal education in engineering colleges an additional year or two may have to be added to the present four-year term.

Eventual results to be expected are: greatly corrected thinking due to objective study of history, religion and philosophy resulting in world federation with abolition of wars, establishment of free trade, freedom of religion, tending toward higher and yet higher plane of clear and free thinking, the steady advance of science for the benefit of mankind and not for destruction.

E. V. THOR (M '43)

(Engineering department, Canadian Westinghouse Company, Ltd., Hamilton, Ontario, Canada)

NEW BOOKS . . .

The following new books are among those recently received at the Engineering Societies Library. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books in question.

ENGINEERING ALLOYS, NAMES, PROPERTIES, USES. 2nd edition. By N. E. Woldman and R. J. Metzler. American Society for Metals, Cleveland, Ohio, 1945. 832 pages, tables, 9¾ by 6 inches, cloth, $10. Section I of this compilation is an alphabetical list of alloys with corresponding serial numbers. In the more than 400 pages of Section II are given the alloy trade name, composition, properties, uses, and key numbers designating the manufacturers. The alloys are here listed by serial number. Section III is an alphabetical subject index of special characteristics and typical uses. Section IV is a directory of manufacturers with their addresses and a summary of the alloys produced by each.

TABLES OF ASSOCIATED LEGENDRE FUNCTIONS. By the Mathematical Tables Project, under the sponsorship of the National Bureau of Standards. Columbia University Press, New York, 1945. Pages xlvi + 306, tables, 11 by 7¾ inches, cloth, $5. The present volume of a series of mathematical tables was produced to meet needs for a table of Legendre functions to about six significant figures at intervals of 0.1.

TECHNOLOGY OF PLASTICS AND RESINS. By J. P. Mason and J. F. Manning. D. Van Nostrand Company, New York, 1945. 493 pages, illustrated, diagrams, charts, tables, 9¾ by 6 inches, cloth, $6.50. The first section discusses the resinous and plastic states. In the second section, the methods of preparation and the properties and uses of the more important resins and plastics are covered, and the third section describes fabrication techniques.

THEORY OF SOUND. 2nd edition. By J. W. Strutt, Baron Rayleigh. Dover Publications, New York, 1945. 984 pages, diagrams, tables, 8½ by 5½ inches, cloth, $4.95. Originally published in two volumes, this treatise is now re-issued in one volume with a historical introduction. The first half is devoted to the vibrations of dynamical systems. The second half covers a variety of topics ranging from aerial vibrations, through fluid friction, to the facts and theories of the process of hearing.

TRANSMISSION LINES, DESIGN, CONSTRUCTION AND PERFORMANCE. By F. C. DeWeese. McGraw-Hill Book Company, London and New York, 1945. 297 pages, illustrated, diagrams, charts, tables, 8½ by 5½ inches, cloth, $3.50. With clear explanation, illustrative examples, and typical problems, this book presents both the fundamental and the more involved aspects of electric power transmission engineering. It provides data and material applicable not only to transmission line problems but also to other problems of a similar nature.

WAVEFORM ANALYSIS, A GUIDE TO THE INTERPRETATION OF PERIODIC WAVES, INCLUDING VIBRATION RECORDS. By R. G. Manley. John Wiley & Sons, New York; Chapman & Hall, London, 1945. 275 pages, illustrated, diagrams, charts, tables, 8¾ by 5½ inches, cloth, $4. Although this book is in the nature of a guide rather than a comprehensive treatise, it includes sufficient basic theory and methods of analysis for the student to acquire a groundwork of knowledge concerning the properties of complex waveforms. The envelope method of analysis is presented in detail, with subsequent discussion of other methods

WILLIS RODNEY WHITNEY, PIONEER OF INDUSTRIAL RESEARCH. By J. T. Broderick. Foreword by K. T. Compton. Fort Orange Press, Albany, N. Y., 1945. 324 pages, illustrated, 8½ by 5½ inches, cloth, $3. This biography covers Willis R. Whitney's life up to and during the time he was director of the research laboratory of the General Electric Company. Much of the book is in Mr. Whitney's own words from addresses or letters.

URANIUM and ATOMIC POWER. By J. De Ment and H. C. Dake. Chemical Publishing Company, Brooklyn, N. Y., 1945. 343 pages, illustrated, diagrams, charts, tables, 9 by 5½ inches, cloth, $4. A brief discussion of the background and possibilities of atomic power is followed by chapters on the constitution of uranium minerals and prospecting methods. The physics and chemistry of uranium as well as the methods used in its detection and determination are included. A large bibliography of original sources of information and a number of tables of useful data are appended.

PAMPHLETS . . .

The following recently issued pamphlets may be of interest to readers of "Electrical Engineering." All inquiries should be addressed to the issuers.

Material-Handling Handbook. Electric Industrial Truck Association, 209 South Wells Street, Chicago 4, Ill., 56 pages.

Radar on Wings. Philco Corporation, Philadelphia, Pa., December 1945, 32 pages.

An Examination of the Department of State's Proposals for Expansion of World Trade and Employment. The American Tariff League, 19 West 44th Street, New York 18, N. Y., 26 pages.

Methods of Testing and Protecting Eyesight in Industry. Prepared by the Industrial Health Section. Policyholders Service Bureau, Metropolitan Life Insurance Company, 1 Madison Avenue, New York 10, N. Y.

FTR Nomographs for Engineers (second set of a series). Federal Telephone and Radio Corporation, Newark 1, N. J., 16 nomographs.

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

Investigation of Arc Starting Characteristics of D-C Welders With Reference to Electrode Freezing

JOSEPH M. TYRNER
ASSOCIATE AIEE

Synopsis: A method for investigating the starting characteristics of an arc in d-c arc welding was developed and equipment was designed and built to simulate the behavior of an operator in starting such an arc. This testing equipment was used to compare the arc striking ability and the arc freezing tendency of an electrode when used with various types of welding generators. It was found that the determining factor is the electrode contact duration, that is, the time during which the operator leaves electrode and work in contact when he attempts to start an arc. Generators, to be satisfactory, should permit at least 40 milliseconds contact duration. Where the permissible contact duration between work and electrode is less than 40 milliseconds, only experienced welders are able to start an arc. Less trained men freeze the electrode to the work piece in a large percentage of their attempts. Five generators of different design were tested with the apparatus. Oscillograms of the current surge during the contact period were taken and the freezing point marked on the curves. It was found that the location of the freezing point depends on the shape of the current surge. Characteristics of a welding generator as developed in these tests which yield good striking and nonfreezing results are not contradictory to good general welding characteristics.

SUCCESS IN STARTING an arc using power from a d-c welding generator does not depend on the electric circuit alone, but also to a great extent on the skill of the operator. An experienced man has fewer failures than an untrained one. If we want to design an apparatus with something like "adjustable operator skill" we have to analyze the skill of a welder. We find that operators when striking an arc may differ in the contact pressure they exert, and also in the time they leave the electrode in contact with the work.

As far as the contact pressure is concerned, it is reasonable to assume that every operator tries to keep the contact pressure as low as possible in order to avoid freezing.

On the other hand, the aptitude of the man determines the duration of the contact between electrode and work piece. Therefore, it seems justified to accept this contact duration as the predominant characteristic of his skill.

With the foregoing in view, an apparatus was built which makes contact between the electrode and work for an adjustable and measurable duration. Figures 1 to 3 show various views of the apparatus. Figure 4 is a diagrammatic picture of it.

The apparatus consists of three parts as shown in Figure 4 numbered 1, 2, and 3. These three parts may move independently around the common axis *A–A*. Part 1 is a pendulum, on the upper extension of which an adjustable bracket (5) together with a chuck (6) is provided. The test electrode (7) is clamped in this chuck (6). The pendulum is kept in a raised position as long as the electromagnet (8) is excited to hold the armature (9). If the circuit of the coil (10) is opened, the magnet (8) releases the armature and the pendulum is free to swing.

Part 2 is the support of the work piece (11), which is used for the freezing test with the electrode (7). The weight (12) on part 2 tends to turn it counterclockwise, but part 2 is held in approximately horizontal position by the bracket (13), which rests on part 3.

The position of part 3 may be adjusted by the stop (15), against which it is held by the weight (14). In this way, the stop (15) establishes not only the position of part 3, but by means of the bracket (13), the position of part 2 as well.

When the pendulum (1) swings in a clockwise direction, the electrode (7) eventually reaches the test piece (11) and makes contact. The impact of the electrode (7), striking against the test piece (11), moves part 2 clockwise, lifting the bracket (13) from part 2. Electrode and test piece stay in contact until, on the return swing, the bracket (13) touches part 3 again. This stops part 2 and electrode and test piece become separated. In this way, the position of part 3, adjusted by the stop (15), determines the length of the contact duration. If the electrode (7) freezes to the test piece (11), the support (2) must follow, even after the bracket (13) reaches part 3. In this case, part 3 is pushed from the stop (15) and the weight (14) is lifted.

It is obvious that one weight (12) controls the contact pressure of electrode and test piece while the force which tends to separate electrode and test piece is determined by the other weight (14).

Contact pressure and breakaway force were not varied during the experiments. They were adjusted to conditions comparable to actual welding as performed by an experienced operator.

The contact duration is measured by the cycle counter (16). If the switch is in its "up" position, an a-c circuit through the cycle counter is closed as long as electrode and test piece are in contact. Swings of the pendulum with the switch in its upper position are used to adjust the contact time by setting the stop (15). The operator is protected from electric shock by the limit switch (18), which keeps the alternating voltage from the electrode-test piece gap, as long as the pendulum is held by the electromagnet (8).

The actual freezing test is made by putting one switch (17) into its down position. This removes the alternating voltage from the electrode-test piece gap and applies it to the holding coil (19) of contactor (20), which connects the genera-

Paper 46-12, recommended by the AIEE committee on electric welding for presentation at the AIEE winter convention, New York, N. Y., January 21–25, 1946. Manuscript submitted September 13, 1945; made available for printing December 11, 1945.

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The author acknowledges and appreciates the cooperation given by J. J. Crowe, assistant vice-president, and E. E. Tizzi of the apparatus research department, and the assistance of E. H. Cushman who built the apparatus and ran the tests covered by this paper. Acknowledgment is made also of the encouragement given to the investigation by C. I. MacGuffie, R. F. Wyer, and R. C. Freeman.

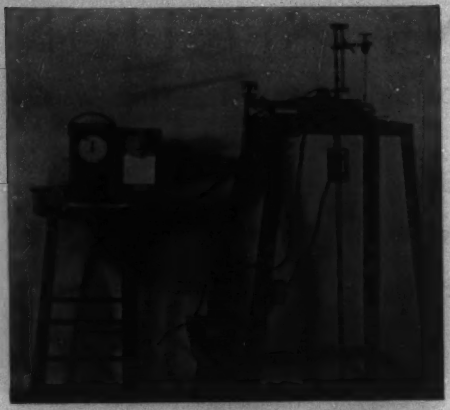

Figure 1. Apparatus with cycle counter

tor being investigated to the apparatus. Another switch (18), in this case, prevents energization of the coil as long as the pendulum is held by the solenoid. Thus, the operator is protected against an accidental flash. The circuit of the holding coil contains a second limit switch (25), which is opened by the movement of part 3 in case of freezing. This terminates the flow of welding current through the short circuit of electrode and test piece. If the electrode does not freeze, the lengthening of the arc drawn by the electrode breaks the circuit automatically and no switch is necessary.

Tests are initiated with the push button (24) which breaks the circuit of the coil (10) of the electromagnet (8).

The coil (10) of the electromagnet (8) is energized by direct current from the welding generator. It was found that the slight vibrations caused by an a-c magnet at that place falsify the test results.

The contact duration during the freezing test can be checked by taking an oscillogram as shown in Figure 5.

Procedure of Test

The operator clamps an electrode in the chuck (6) and provides a proper test piece (11). He adjusts the electrode roughly by moving the sleeve of the bracket (5) on the pendulum. The switch (17) is put into its "up" position. The button (24) is pressed and the pendulum released. The contact time is observed on the cycle counter. Then the stop (15) is adjusted to bring the contact time nearer to the desired value and the test repeated. After several trials, the apparatus is ready for test. To increase accuracy three timing swings are made without resetting the counter to zero. The reading thus becomes the sum of three contact times and one third of this value is considered to be the average contact time for the actual striking test. After the apparatus is adjusted to the desired contact time, switch (17) is put into its "down" position for the application of welding power. The next swing produces either a flash or the electrode freezes to the test piece.

A series of tests for different contact durations is run with a fairly large number of tests for each setting. For each setting, a number of freezings and a number of flashes are obtained. The frequency of freezings is calculated and plotted as a function of the contact duration. A curve thus is obtained which moves from a low percentage of freezings, at short durations, to a high percentage at long durations. The change from the low percentage to the high percentage is sudden. The contact duration yielding an equal number of freezings and flashes is called arbitrarily the "freezing time" of the generator.

Influence of Circuit Setting, Electrode Size, and Electrode Coating

It can be shown theoretically that the curve of the surge does not change much with different current settings. Therefore, the freezing time also does not change. The electrode size has no influence because the contact in the testing apparatus is a point contact only, and it

Figure 2. Front view of apparatus

Figure 3. Rear view of apparatus

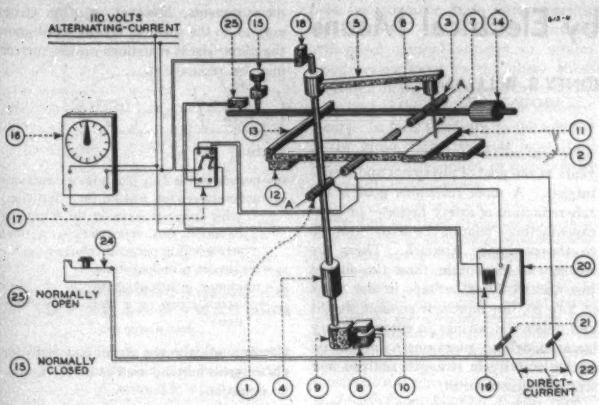

Figure 4. Diagrammatic picture of apparatus

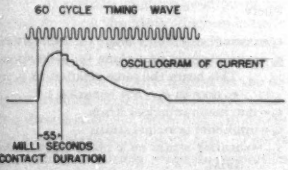

Figure 5. Oscillogram of current

does not matter whether the contact-making point is on a 1/16-inch diameter or on a 1/8-inch diameter electrode.

The coating has no influence provided the coating is kept away from the point of contact.

Consequently, it was decided to make all tests with bare electrodes of 3/32-inch diameter with generator settings of about 70 amperes welding current.

A few tests were made with other settings and with electrodes of other sizes and with different coatings. They confirmed these conclusions.

In order to eliminate the influence of scale, electrodes were ground square and test pieces cleaned thoroughly.

Generator Tests

Four commercial and one experimental generator with different circuits, but all of the same rating, were tested. All generators were set for the same welding output. The test results are shown in Table I.

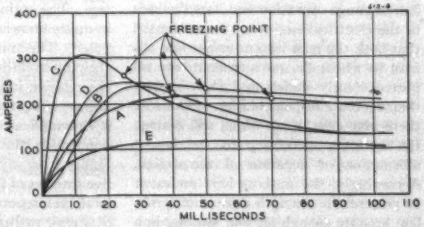

Figure 6. Threshold values of contact time

Freezing of electrodes

Table I

Generator Tested	Critical Contact Time in Milliseconds
A	70
B	40
C (Generator *B* without external reactor)	25
D	50
E (Experimental)	1,000

In order to correlate these tests with the properties of the different electric circuits, open circuit short circuit transients of the five generators were determined by taking oscillograms. The freezing times are marked on the current curves shown in Figure 6. These curves show that freezing occurs some time after the highest point of the surge. The explanation may be that, during the decline of the surge, not enough heat is furnished to keep in a molten state the metal which melted at the height of the surge. The conclusion would be that the generator should reach its maximum current as late as possible. This is corroborated by the curve of generator *E* which approaches the maximum short circuit extremely slowly. Tests show that this generator practically never freezes.

Operator Requirements

The requirements of the operator were determined by watching the reaction of different men to the generators which had been tested.

It was found that the average operator is satisfied with a generator which does not freeze during the first 40 milliseconds. Generators with contact times as long as 70 milliseconds are very good. Everything beyond that is excellent.

Simplified Tests

An apparatus of the kind described here usually is not available and it would be advantageous to be able to use standard equipment to judge a generator for its starting properties. Fortunately, an oscillogram of an open circuit short circuit test yields sufficient information. The curves of Figure 6 show that the critical time is approximately twice the time the generator needs to reach the crest of the surge. If we accept this without trying to find any reason for it, we may say that a generator should take at least 20 milliseconds to reach the crest of the surge. If it takes less, the generator is difficult to handle. On the other hand, a longer time indicates a generator with improved starting properties.

Stress Measurement by Electrical Means

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THE ADVENT of electric strain gauges[1] suitable for the measurement of mechanical performance on a strength basis not only has widened the field of the electrical engineer with regard to equipment and techniques but gradually has imposed upon him a responsibility to the aeronautical or mechanical engineer in his role as interpreter. For if the designer turns to electric strain gauges (and by this is meant herein the bonded wire gauge,[2] unless otherwise stated) for verification of his work, it is only natural for him eventually to leave the whole problem of gauge operation and data analysis to the electrical engineer. It is essential that both the man who measures and the man to whom the measurements are reported clearly understand the scope of their separate responsibilities. Otherwise there may exist a gap which will destroy the accuracy necessary to the honest affirmation or negation of the design. Accordingly, the authors here endeavor to present the strength evaluation problem broadly enough for one working in a relatively narrow element of it to appreciate the requirements of the whole, while emphasizing the electrical aspects primarily and keeping always in sharp focus the prime requisite, accuracy.

The Mechanical Problem

Design

As Sir Charles Darwin explained in his illuminating James Forrest lecture[3] entitled "The Extreme Properties of Matter" there is more opportunity for improvement in the strength of materials than in the refinement of almost any other property of materials. The theoretical ultimate shear strength of steel as given by Darwin is the shear modulus of elasticity divided by 2π. Depending on the grade of steel, this represents a possible improvement of 10 to 50 times, which values well might be assumed to be applicable to steel strength in general. These are figures to conjure with, but their ultimate realization probably will stand for years as the goal of physicists and metallurgists. A more realizable goal is the safe reduction of safety factors—or ignorance factors—relating the actual strength to the necessary strength. These are smaller in magnitude than the figures just quoted, lying perhaps in the range of 2 to 20, but represent possible weight and dimension savings in every industry large enough to guarantee a broad and lasting activity in strength analysis and strength measurement.

This, then, is the beginning of the problem. The optimum design stems from an accurate knowledge of the loads to be imposed. The quiescent and dynamic loads, their interrelation, the expected life and the relative importance of an occasional failure, make this problem complex. And it is complicated many-fold by that imponderable, the proper theory of failure.[4] Suffice it to say that there exist at least five theories of failure, but most test data have been reported and analyzed in terms of stress, rather than strain, energy, or other parameters. As most loading in combined stress studies appears to have been performed in terms of stress, it is reasonable to evaluate strength in terms of stress. The available literature tends to indicate that there is not enough evidence to substantiate any one general theory of failure, although certain theories appear to be more applicable than others depending upon the particular materials and loading encountered. The designer's problems, then, are the first source of error, and it is the designer's responsibility to the measurer to acquaint the latter with enough of the theory so that the proper measurements can be made. This may be as simple as a statement to the effect that the results are to be reported in terms of stress, or of strain. The nature of the available types of measurement is such that it often is not possible to correct data from one type to another after the gauge installation has been made.

Stress–Strain Relations for Plane Stress

The relations existing between the three mutually orthogonal stresses σ_x, σ_y and σ_z in the x, y, and z directions respectively and the three corresponding strains ϵ_x, ϵ_y, and ϵ_z may be found in many texts.[5] For any work involving surface measurements, however, σ_z (the stress normal to the surface) is zero, whereupon the plane stress equations on the surface may be reduced[6] to

$$\left(\sigma_x - \frac{\sigma_p + \sigma_q}{2}\right)^2 + \tau_{xy}^2 = \left(\frac{\sigma_p - \sigma_q}{2}\right)^2 \qquad (1)$$

where

σ_x = normal stress on x plane (in x direction)
σ_y = normal stress on y plane (in y direction) (this does not occur in the foregoing equation but represents a normal stress acting perpendicularly to σ_x)
σ_p = maximum principal stress
σ_q = minimum principal stress
τ_{xy} = shearing stress on x plane (in y direction)

Correspondingly, the strain equations for plane stress may be used to derive a similar equation:

$$\left(\epsilon_x - \frac{\epsilon_p + \epsilon_q}{2}\right)^2 + \left(\frac{\gamma_{xy}}{2}\right)^2 = \left(\frac{\epsilon_p - \epsilon_q}{2}\right)^2 \qquad (2)$$

where

ϵ_x = normal strain on x plane (in x direction)
ϵ_y = normal strain on y plane (in y direction) This bears the same relation to ϵ_x as σ_y does to σ_x. See equation 1
ϵ_p = maximum principal strain
ϵ_q = minimum principal strain
γ_{xy} = shearing strain on x plane (in y direction)

It will be appreciated that equation 1 and equation 2 both define circles, and it will be observed that each circle equation is of the form

$$(x-h)^2 + y^2 = r^2 \qquad (3)$$

where h represents the circle center and r the circle radius. Constructing these two circles, known as the Mohr circles of stress and of strain respectively, will show why individual stress measurements cannot be converted directly to strain measurements, unless enough data (three stress or three strain vector measurements at a point) are taken to draw the circles of stress and of strain. This is understood better when it is appreciated that any given measurement represents the projection on an axis of some point on the circle circumference. Normal stresses and strains are projected as points on the N axis while shear stresses and strains appear as points on the S axis. These two circles may be drawn concentrically,[6] as shown in Figure 1, provided that the scales are chosen so that the ratio of stress units to strain units is as $E_T/(1-\mu)$ where E_T is the modulus of elasticity in tension or compression, and μ is Poisson's ratio. When the circles are drawn in this manner it will be found that the stress circle radius is smaller than the strain

Paper 46-60, recommended by the AIEE committee on instruments and measurements for presentation at the AIEE winter convention, New York, N. Y., January 21–25, 1946. Manuscript submitted July 14, 1945; made available for printing December 11, 1945.

Robert E. Kern and Sidney B. Williams, assistant project engineer, are both in the propeller division, Curtiss-Wright Corporation, Caldwell, N. J.

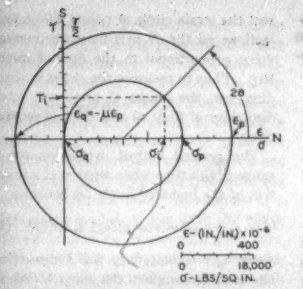

Figure 1. The Mohr circles of stress and strain for a simple axial stress of +30,000 pounds per square inch

Young's modulus is taken to be 30×10^6 pounds per square inch and Poisson's ratio to be 0.3

circle radius in the ratio of $(1 - \mu)/(1 + \mu)$ and the angular position of the point (σ, τ) on the Mohr diagram is twice that of the physical direction of measurement, so that if a measurement be made in the direction θ (with respect to the direction of principal stress) the corresponding direction on the circle diagram makes an angle of 2θ with the N axis. This is reasonable because a complete revolution around the Mohr circle must represent a 180-degree rotation of the measuring device. The concept of the two Mohr circles is not appreciated by many workers in the field, and it is perhaps for this reason that difficulty with the stress-strain relation is prevalent. It is because of the Poisson or lateral contraction exhibited by a stressed member that the ratio of stress to strain is not constant even while operating in the elastic state. For example, the ratio of stress to strain in the direction of the load (σ_p/ϵ_p) for a simple tension test is by definition equal to the modulus of elasticity, E_T, but the ratio of stress to strain in a direction perpendicular to the load is zero. The load has no component in this direction $(\sigma_q = 0)$ but the lateral strain $(\epsilon_q = -\mu\epsilon_p)$ is finite and opposite in sign. Further examination of Figure 1 will show that the simple tension case is represented with σ_p (+30,000 pounds per square inch) positive and σ_q zero. It can be seen that $\epsilon_q = -\mu\epsilon_p$ and particularly that the ratio σ_q/ϵ_q is not constant as the radius is rotated, and were the center of the circles displaced somewhat $(\sigma_q \neq 0)$ even the ratio $\sigma_p/\epsilon_p = E_T$ would not hold.

Thus far, only *normal* stresses and strains have been discussed. *Shear* stresses and strains cannot be detected as a change in length, but can be calculated from two stress or strain measurements, the difference between two mutually orthogonal normal stresses or strains being proportional to the shear stress measured on the plane whose direction bisects that of the two orthogonal measurements. In fact, this leads to the solution of the Mohr circle diagrams from three normal strains separated in direction by increments of 45 degrees:

As the first and third strains are orthogonal they must lie on extremities of some diameter of the circle, and consequently their arithmetic mean must coincide with the circle center. Now, the difference of the first and third (orthogonal) normal strains is equal to the shearing strain associated with the second normal strain, since the direction of the latter bisects that of the first and third strains. As dictated by the second term of equation 2, half of this value is plotted as an ordinate at the abscissa corresponding to the second strain, thus locating the point $(\epsilon_t, \gamma_{t2}/2)$ on the circumference, and the radius drawn from the center to this point just found must be perpendicular to the diameter determining the points corresponding to the first and third measurements as the 45-degree increments on the specimen must exist as right angles on the strain circle diagram. The solution is completed by constructing the stress circle with its smaller radius, $(1-\mu)/(1+\mu)$ as large as the strain circle radius, whereupon the various points (σ_t, τ_t) can be obtained, although the most pertinent information usually consists of the extremes of the circle dimensions and the angle 2θ (measured counterclockwise from the direction of the first strain to the N or normal axis). The method is checked by projecting the three solution points located on the strain (or stress) circle circumference to the N axis; if the construction has been made correctly the projections will coincide with the three measured strains (or stresses). The word "stresses" is used advisedly because, with the proper gauges, stresses can be measured directly.

Electrical Measurements: The Bonded Wire Gauge

Strength measurements can be obtained from numerous types of gauges[7] but the principles controlling the use of the bonded wire resistance gauge will apply generally to other methods, except that the resistance-type units are characterized by lower mechanical inertia and lower voltage output than most. The bonded wire gauge, commonly referred to as the wire strain gauge, has for its principle of operation the variation in resistance of a fine metallic filament bonded to the surface whose deformations are to be measured. In order to make its installation practical the filament first is cemented to a paper "carrier" which, in turn, is cemented to the specimen. This carrier is in no way necessary to the operation of the gauge. In fact its elimination

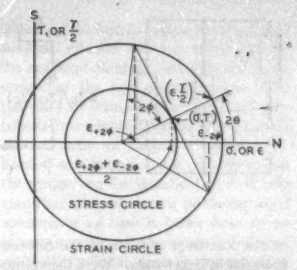

Figure 2. The Mohr circles of stress and of strain on which is shown graphically the manner whereby the Vee type of gauge can be made to yield a result proportional to the stress in the direction of its axis

would be desirable so that the filament might be closer to the specimen, while also allaying the danger of improper transfer of the "mechanical signal" to the active element of fine wire. Actually, the wire first is wound in the form of a grid to which wire leads are joined, after which the grid and leads are placed against the paper carrier for cementing. After the gauge (filament plus cement plus carrier) is cemented to the specimen the assembly acts as if it were part of the specimen in that it accepts uniformly the dimensional changes, both positive and negative, of the deformed surface, while offering negligible restraint in so doing because of its small mass and low effective moduli of elasticity. This action is possible because the dimensions of the wire filament are defined by the matrix of cement in which it is embedded, and it is essential that in the design of such a gauge the wire diameter be small enough so that this effect is achieved. Otherwise compressive strains might result in buckling of the wire with resultant destruction of the bond. This situation is somewhat comparable to the reinforcing rods in a concrete beam, wherein the concrete transmits the tension to the rods, and prevents the rods from buckling in compression (assuming that compressive loads might be placed on such a part of the beam). This transmission of the mechanical signal to the wire results in a permissible amplitude, with linear resistance-versus-strain response, in excess of the proportional limit of the filament material. This amplitude is represented by the manufacturer to approximate one per cent with negligible change in unstrained resistance, and to attain values of two to three per cent for linear operation without complete zero return. The gauge change of resistance is linear and consistent, but not explainable in terms

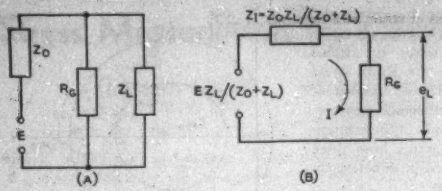

Figure 3. Fundamental gauge circuit (A) and its equivalent (B)

of the known properties of the filament material in larger sizes. Were the volume resistivity of the wire to be constant with respect to elastic strains it would be reasonable to expect the unit relative change in resistance (dR/R) for unit relative change in length (unit strain, ϵ) to be $(1 + 2\mu)$, where μ = Poisson's ratio. This ratio $dR/R\epsilon$ is defined as S, the gauge sensitivity, and because Poisson's ratio has a theoretical maximum of 0.5, the sensitivity should not exceed 2.0. Actually, certain gauges (made of "Advance" alloy) have such a sensitivity but many gauges are made with sensitivities lying in the range of -5 to $+3.5$, a fact which either contradicts the 0.5 maximum for Poisson's ratio or sheds some interesting light on the volume resistivity of fine wire materials as a function of stress. To date this anomaly is unsolved but may yield to electron microscopy (for use in determining Poisson's ratio for the strained filament). As a matter of interest the operating current density in the usual gauge wire is of the order of 25,000–50,000 amperes per square inch.

Bonded wire gauges are manufactured to meet a demand which requires both thermal stability and sensitivity. Currently these are conflicting requirements because the most sensitive materials (of which the invar, "Iso-elastic," an alloy originally developed for constant modulus of elasticity versus temperature, is representative) are very sensitive to temperature changes. Thermal stability implies that the sum of the effect of differential coefficient of expansion between the filament and the strained surface and the effect of filament temperature coefficient of resistance approaches zero, obviously a function dependent upon the characteristics of the material upon which the gauge is mounted. It is not surprising, therefore, that Advance wire gauges are thermally quite stable on steel, not as stable on aluminum, and not at all stable when suspended in air and subject to the erratic behavior of the unmounted paper carrier, the latter condition representing an academic case. Currently available are the thermally stable Advance gauges with a sensitivity of approximately 2.0 and suitable for all types of deformation measurement, and the Iso-elastic gauges with a sensitivity of 3.5 but suitable only for dynamic work. The latter type are inherently of a higher resistance, permitting generally a higher voltage drop, which condition may be interpreted as a further increase in sensitivity when the load is effectively an open circuit, such as a vacuum tube.

Gauges are available in a wide variety of dimensions and resistances ranging from units 1/16 inch square with 60 ohms resistance to others six inches long (300 ohms) and again some approximately 1/2 inch square with a resistance of 2,000 ohms. Still others, termed rosettes, are arranged in groups of two, three, or four units mounted close together, but oriented in different directions, for the measurement of the complete state of stress by means of the Mohr circle diagram.

The Stress Gauge

In a biaxial stress field the measurement of stress can be simplified greatly by the use of a gauge which responds both to strains parallel and strains perpendicular to the gauge axis[6]. Provided that the gauge specific transverse sensitivity (the ratio of the lateral to the axial response of the gauge) is equal to Poisson's ratio, the gauge output is continuously proportional to the stress in the direction of the gauge axis. This is in accordance[5] with equation 4:

$$\sigma_x = \frac{E_T}{1-\mu^2}(\epsilon_x + \mu\epsilon_y) \qquad (4)$$

The proof of the stress response characteristic of the gauge is shown conveniently for a particular geometric pattern actually used in commercial gauges. This pattern has the wire arranged in a V, the angle between the wires being selected so that the average of the strains from each arm of the V yields an output proportional to the stress.

The measurement of stress in the direction θ with respect to the direction of the principal axis, requires that the projection of the point (σ, τ) in Figure 2 be determined. A tangent to the stress circle drawn at the point (σ, τ), will intersect the strain circle at points whose projections on the N axis have an average value proportional to the desired quantity. Thus to measure the stress in the θ direction, the gauge V arms will have directions of $(\theta + \phi)$ and $(\theta - \phi)$ respectively.

The general output expression for a gauge of this type when written as a function of the included angle 2ϕ becomes

$$\tfrac{1}{2}(\epsilon_{+2\phi} + \epsilon_{-2\phi}) = (\cos^2\phi)(\epsilon_x + \epsilon_y \tan^2\phi) \qquad (5)$$

where ϵ_x is oriented in the θ direction. The included angle of the gauge V, 2ϕ, is chosen so that $\tan^2\phi$ equals Poisson's ratio for the tested material. Then the right-hand member of equation 5 reduces to $\sigma_x/[E_T/(1-\mu)]$. Steel, for example, with a Poisson's ratio of 0.28, requires an angle of about 55 degrees, the exact angle being determined by methods of manufacture. This type of stress gauge is used extensively in the testing of hollow steel aircraft propeller blades.

For the stress gauge, the expression which relates the relative change in gauge resistance to the stress producing it is

$$dR_G/R_G = F\epsilon' \qquad (6)$$

where R_G is the gauge resistance and ϵ' is the ratio of stress along the gauge axis to Young's modulus for the material upon which the gauge is mounted. The stress gauge factor F has the following relationship with S, the strain gauge factor:

$$F = (1-\mu)S \qquad (7)$$

It can be shown from equation 5 that the ratio of the output of a stress gauge to the output of a strain gauge of equivalent wire length and resistance and under uniaxial stress is $(1 - \mu)$.

The use of stress gauges can reduce materially the effort required to determine stresses. The direct indication of stress is of particular importance when complex vibratory stresses are measured; under such conditions two strain records separately recorded would have to be converted to stress through a point-by-point conversion if the instantaneous stresses could not be indicated directly.

Errors of Location and Installation

Before proceeding to a discussion of the electric circuits of resistance wire gauges it is appropriate to discuss the theoretical and mechanical considerations which may contribute to inaccuracy in the final conclusions. These may be called the errors of location and installation. That is, the output of the gauges must be indicative of the most critical stress in the part, the stress at the points where failure will occur

if it is to occur. Presumably this will be on the surface at the geometrical center of one of the gauges, though many failures do not start at the surface. On a test specimen such as a hollow steel propeller blade an error of a fraction of an inch in location can produce a change in output of 100 per cent or more, and since any one gauge will cover less than one-tenth per cent of the total area, the location of a few dozen gauges or less over the whole propeller must be chosen with great care. Moreover, if only one gauge is to be located at any one point, the gauge axis orientation is also important, as can be judged by Mohr circle theory. Fortunately, some knowledge of critical areas and stress direction is often available from photoelastic[4,5] and brittle lacquer[6] ("Stresscoat") studies, discussions of which are beyond the scope of this article. The former method is not convenient for vibratory work and both tend to be laboratory procedures so that it is not always possible to simulate field loadings. Having chosen the proper location it will not always be possible to place gauges where desired due either to inaccessibility or to the physical size of the gauge, which may be so large as to cause an error by integrating the stress or strain over the gauge length when the stress gradient is such as to be masked by the use of too large a gauge length. The availability of shorter gauges has improved this latter situation but sometimes the minimum size of gauge is dictated by electric circuit background noise, the higher resistance gauges being required to produce sufficient signal to result in an acceptable signal-to-noise ratio. This difficulty is probably peculiar to tests on rotating objects such as aircraft propellers, which exhibit accessibility problems also, since flight measurements commonly are made inside the hollow blades, even near the tip, and some work has been done within the hub itself. (Flight stress measurements are made on nearly every propeller–engine–aircraft combination before final acceptance of the design by the customer.) One of the most common sources of gauge error lies in the neutral-axis correction, which is applicable to any survey involving bending stresses. The classical bending-beam theory shows that the stress is proportional to the distance from the beam neutral axis (plane of zero stress); in consequence, bending-stress measurements made at any distance from the neutral axis but that of the surface will be incorrect in direct proportion to this distance. Since the gauge acts as a part of the tested material, accurate bending-stress measurements must correct for the effective gauge elevation above the surface. The diameter of the wire filament is about 0.001 inch and its centerline is perhaps 0.003 inch above the tested surface due primarily to the thickness of the paper carrier. That this is not negligible may be appreciated from a consideration of measurements on a 0.060-inch plate in bending, where the 0.003-inch elevation will cause an exaggeration of ten per cent if the neutral axis is in the central plane of the plate (pure bending). When bending is combined with tension or compression neutral axis error sometimes can be avoided by mounting identical gauges on opposite faces of the plate; their sum eliminates the bending component to yield the tension or compression while their difference eliminates the tension or compression and thermal components, though the resultant bending measurement still is subject to neutral axis error. Returning to the problem of installation, or mounting, it hardly should be necessary to state that the proper bonding of the gauge to the tested surface is of extreme importance to a successful technique. Conservative instructions are supplied by the manufacturer, and occasionally the time allowed for curing or drying of the adhesive may be shortened, but in all cases care should be taken to insure proper preparation of the tested surface (preferably roughening with fine sandpaper plus cleaning with acetone) and adequate application of the adhesive. In the interest of quick drying there is a tendency to apply the adhesive sparingly, which may result in an incomplete bond. Poor surface preparation sometimes is evidenced by the flaking off of a gauge after the test has been completed and the tested parts are no longer available for retest. Where practical the installed gauges may be checked by a calibration with a known load, or another type of gauge, such as the Tuckerman optical strain gauge, may be placed over the installed gauge and the specimen loaded to produce a given strain. The Tuckerman gauge is relatively small and light, and often may be applied with no more force than its own weight, but it is distinctly a laboratory instrument (more often used as a standard).

Other sources of error contributing uncertainty and which pertain more directly to the tested material itself include "locked-in" or residual stresses, the deviation of the remainder of the "universe" from the sample tested, the elastic modulus (if stresses are to be computed), and "creep."[10] Unless the material is in a "dead-soft" or perfectly annealed condition there usually will be certain unrelieved or locked-in stresses remaining. Residual stresses will not affect greatly the readings obtained but will determine somewhat the interpretation read from the data by the designer, as they contribute to or inhibit failure. The actual measurement of locked-in stresses by bonded wire gauges is not possible unless the gauge can be installed prior to the manufacturing operation producing such stresses, or as now is being done to an increasing extent,[11] the gauge is installed while the residual stress is present, after which most of the restraining material is removed carefully and the local stress under the gauge relieved. The indicated stress pattern is then a "negative" of the locked-in pattern.

Young's modulus, E_Y, occurs in the equation relating stress and strain. For the two-dimensional (biaxial) case this is in accordance with equation 4. But the stress–strain relationship for many engineering materials is distinctly nonlinear (aside from the fact that E_Y at zero load is subject to a degree of uncertainty) so that an indicated vibration stress of $\pm$10,000 pounds per square inch, when no steady load existed, might differ from the indicated value when a steady load of 50,000 pounds per square inch was applied simultaneously. Such considerations might be affected differently for steady locked-in or surface stress than for uniformly-distributed steady stress. Modulus correction of this nature is not known to the authors but would have to be considered in evaluating closely the probable error. Creep is the phenomenon of gradual continued deformation at constant load and is ordinarily negligible in steel at low temperatures (below 200 degrees Fahrenheit) but may be appreciable in some other materials such as lead, plastics, and gauge bonding agents when large deformations are involved. It may prevent a return to a zero-stress reading, even when the gauge itself is operating properly. It may be obscured by or confused with drift due to poor temperature compensation or the chang-

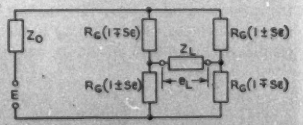

Figure 4. Equiarm strain gauge bridge circuit

Parenthetical term of R_G indicates direction and magnitude of resistance change in each gauge as a function of gauge factor and applied strain

ing leakage characteristics of the electrical insulation, as will be discussed later.

The Electrical Problem

Gauge Circuits

Two general circuits which may be used for the conversion of strain to electrical signal are shown in Figures 3*A* and 4. The simpler circuit of Figure 3*A* often may be used when a knowledge of only transient or vibratory stress or strain is desired, while the bridge circuit of Figure 4 is employed when the steady component with or without the vibratory component is to be determined or when protection from excitation circuit disturbances (as in slip-ring installations) is required.

When vibratory shear, or the difference in strain between two gauges at right angles, must be measured, the "matching" resistor, Z_O, in Figure 3*A* becomes one gauge while the active gauge, R_G, becomes the second of the two required orthogonal strain-sensitive elements. The bridge circuit can be arranged suitably to enable the measurement of total shear, since differential measurements are applicable for shear, torsion, and many bending problems.

Network theorems[12,13] are used conveniently to calculate the voltage which appears when the active circuit elements are strained. Thus the Thévenin equivalent of Figure 3*A*, shown in Figure 3*B*, yields current in the gauge of

$$I=\frac{EZ_L/(Z_O+Z_L)}{R_G+Z_OZ_L/(Z_O+Z_L)}=\frac{EZ_L}{Z_OZ_L+R_G(Z_O+Z_L)} \quad (8)$$

The change in load voltage dE_L due to a change dR_G associated with the strain ϵ is

$$dE_L=e_L=d(IR_G)=IdR_G+R_GdI \quad (9)$$

Evaluating dI (by means of the compensation theorem) and collecting terms,

$$e_L=I\left(\frac{dR_G}{R_G}\right)\frac{R_GZ_OZ_L/(Z_O+Z_L)}{R_G+Z_OZ_L/(Z_O+Z_L)} \quad (10)$$

The sensitivity S of a strain gauge has been defined previously as $dR/R = S\epsilon$. Using this relation together with the fact that the coefficient of $I(dR_G/R_G)$ is the parallel combination of R_G and Z_I, equation 10 is simply

$$e_L=ZIS\epsilon \quad (11a)$$

where $Z = R_GZ_I/(R_G + Z_I)$ evaluated at the strain frequency and I is evaluated from equation 8 at excitation frequency. For practical applications the impedances are entirely resistive, with the load impedance Z_L (usually amplifier input impedance) much greater than the gauge resistance, R_G. The greatest output voltage for a given value of E occurs when the product of ZI (or more commonly RI) is a maximum, that is, when Z_O equals R_G. When it is possible to measure two or four strains which are exactly equal but occur in conjugate pairs as shown in Figure 4, the bridge circuit increases the no-load voltage output above that of Figure 3*A* by two and four times respectively.

The voltage output equation for four active equal bridge arms is developed in a manner similar to that of equation 11a and is

$$e_L=ZIS\epsilon \quad (11b)$$

where Z, just as in equation 11a, is the impedance (at the strain frequency) measured across the terminals of the load impedance Z_L, when other voltage sources in the circuit are not generating but are replaced with their equivalent internal impedances. Expressed explicitly this impedance, Z, is $R_GZ_L/(R_G + Z_L)$. Note that when the load impedance Z_L is large with respect to the gauge resistance, the output voltage e_L is given by the expression $E\epsilon S$, and further, that I is the current of excitation frequency supplied the gauges, or $E/(R_G + Z_O)$.

The quantity $S\epsilon$ may be regarded as an average value determined by the number and characteristics of the gauges acting. If the output from a gauge (due either to its location in the bridge circuit or because of the sign of strain) tends to cancel the effects from another, the algebraic signs of the two quantities $S\epsilon$, associated with the respective gauges, may be regarded as opposite. Thus a bridge with only two active gauges (but these connected in one side of the bridge and subject to equal and opposite strains) will exhibit an output voltage of $e_L = (1/2)ZIS\epsilon$, since two of the four gauges have zero as their effective value of $S\epsilon$.

Output voltage equations 11a and 11b may be examined to ascertain the errors which may result from variation in the controllable parameters. It is immediately evident that errors in E, the excitation voltage, and errors in gauge sensitivity, S, contribute in direct proportion to the error in gauge output voltage. Excitation voltage may be monitored or controlled by the operator; the gauge sensitivity factor is supplied with commercial gauges and usually is guaranteed to plus or minus one per cent.

Since the nominal value of gauge resistance may be subject to as much as a two or three per cent manufacturing tolerance, particularly in those gauges supplied for dynamic work, it is necessary to examine the ZI term in equation 11a to evaluate the effect of changing the gauge resistance. Assuming that the impedances are essentially constant and resistive in the operating portion of the spectrum (a condition necessary for good amplitude-frequency response) and that Z_L is large with respect to Z_O, the relative change in output voltage is

$$de_L/e_L=d(ZIS\epsilon)/ZIS\epsilon=d(ZI)/ZI=-(dR_G/R_G)(R_G-Z_I)/(R_G+Z_I) \quad (12)$$

where Z_I is $Z_LZ_O/(Z_L + Z_O)$ and dR_G/R_G is the relative change in the nominal resistance and not $S\epsilon$, which here is considered constant. The condition R_G equal to Z_I suffices for zero error in calculated output voltage as a function of tolerance in gauge nominal resistance; moreover since Z_L is large in comparison to Z_O, it is possible to have the zero error condition coincide with the maximum output condition by setting Z_O equal to R_G.

As stated previously, measurements of steady strain require that gauge resistance be a function of strain only and be unaffected by temperature or variation in electrical leakage. Temperature effects are eliminated most nearly by using a compensating gauge mounted on material equivalent to the test specimen and subject to the same ambient temperature variations. The compensating gauge may be active or passive but is connected in the bridge arm adjacent to the compensated unit.

Using an unstrained specimen equipped with two nitrocellulose bonded gauges wound with Advance wire, temperature compensation to within two microinches per inch over a range from 70 to 170 degrees Fahrenheit has been attained in the laboratory. However, general practice indicates that two microinches per inch per degree Fahrenheit is a more practical estimate of realizable temperature compensation.

The measurement of vibratory stresses up to a temperature of about 180–200 degrees Fahrenheit is possible with nitrocellulose bonded gauges. A specific case for ±400 microinches per inch of strain showed at 230 degrees Fahrenheit a drop of 30 per cent from the value of apparent gauge factor at 200 degrees Fahrenheit, the difference due to softening of the cement. For elevated temperature operation up to 300 degrees Fahrenheit, resin-bonded gauges are used.

In order to prevent "zero" instability due to absorption of moisture by the gauge or associated leads, it is necessary to weatherproof the installation by first driving off all moisture and then coating or impregnating with a nonhygroscopic

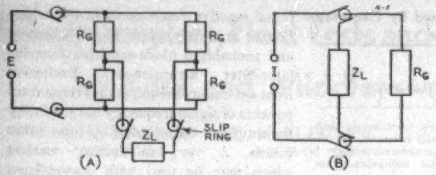

Figure 5. Location of slip rings and related components in a constant-voltage gauge circuit (*A*), and in a constant-current circuit (*B*)

material such as a hydrocarbon wax. A typical gauge, having a resistance of 120 ohms and a sensitivity of 2.0, will change in resistance by only 0.008 ohm when subjected to a stress of 1,000 pounds per square inch in steel (33 microinches per inch). This change also may be produced by a shunt resistance across the gauge of 1.8 megohms (very nearly R_G/Se) thus making evident the necessity for thorough moistureproofing. A value of 1,000 megohms is recommended by the gauge manufacturer. When many gauges are in a circuit possessing one or more common leads, it is often convenient to make provision for measuring the leakage to ground. Such an indication cannot be interpreted explicitly but serves as a warning of changing insulation conditions.

The nitrocellulose, and to a lesser extent the resin base, bonding agents both are subject to creep under prolonged strain and also exhibit slight apparent hysteresis over a stress–strain cycle. Proper application and curing helps reduce creep to a minimum and several preliminary loading cycles usually suffice to make hysteresis effects negligible. The possibility of errors from this source should not be overlooked if readings having a tolerance of five to ten microinches per inch must be obtained. Moreover it is only reasonable to assume that creep difficulties will increase with stress level and temperature.

Special Circuits

When the information as to the state of stress on a rotating member is to be obtained with the aid of sliding contacts, it usually will be necessary to minimize contact resistance effects by arranging a balanced bridge on the rotating element as in Figure 5*A*. Results free from slip-ring interference, especially at high surface speeds, are impossible of achievement if the slip rings are connected directly to make up part of the gauge resistance. Inspection of the current term in equation 11b shows why the bridge circuit of Figure 5*A* is relatively free from effects resulting from variation in resistance of the slip rings supplying the exciting current, and inspection of the impedance term will show how Z_L may be chosen to make the effect of output-circuit slip-ring resistance variation negligible. It is also essential that the slip rings located in the leads which supply the load do not introduce thermal electromotive forces. An alloy consisting of 97 per cent silver and 3 per cent platinum, the latter for hardness, used in conjunction with silver-graphite brushes, has proved very satisfactory under brush pressures of 40 pounds per square inch and surface speeds of about 4,000 feet per minute. Improvement in the strain signal-to-slip-ring noise ratio may be obtained by the use of a bridge-output transformer mounted on the rotating object, provided that the resultant phase and amplitude distortion versus frequency of the signal is negligible. Such a system is suited especially for use with carrier-current excitation.

Constant-current excitation sometimes is employed in slip-ring circuits to overcome the resistance variation in the transfer system. With this method, the output voltage is equal to IdR_G as the component $R_G dI$ no longer is present. The gauge output voltage for constant-current excitation is twice that obtained from constant voltage excitation when the average currents in both cases are equal. Referring to Figure 5*B*, it will be seen that the voltage drop across the slip-ring contact resistance need not be measured as two brushes, one for the excitation current and another for the signal voltage, may be used. It is still possible, however, for thermopotentials arising at the signal brush to mask out the strain voltage unless the proper materials, such as those described in the foregoing, are employed.

To find the stress in a material subject to biaxial stress, it is necessary to take the proper proportions of two orthogonal strains as explained in the discussion of the stress gauge. But if it is desired to measure two orthogonal stresses at a point the purpose perhaps can be served best by using a pair of orthogonal strain gauges with their electric circuits arranged so as to crosstalk mutually the correct lateral or transverse component each into the other (refer to equation 4) to produce the effect of two stress gauges. This arrangement requires a double installation compared to a single stress gauge but yields two stress measurements, which can be taken separately or simultaneously, just as if the strain gauge filaments had been arranged in the path of stress gauge grids and the mutual impedance removed. Both sections of such a

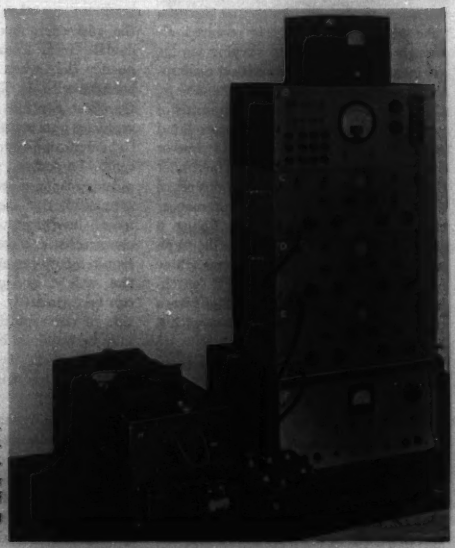

Figure 6. Twelve-channel amplifier-oscillograph equipment showing oscillograph, power supply, three banks of amplifiers, switching panel, and calibrator

circuit must be furnished excitation current, however, even if recorded at separate times. One such arrangement consists of connecting together two gauges, whose directions have the required rectangular relationship, with a common impedance Z_C joining the output or load terminals. If the two gauge circuits (composed entirely of resistive elements) have like components it can be shown that when Z_C is set equal to $R_I(1 + \beta)(1 - \mu)/(\mu - \beta)$ where R_I is $R_G R_O/(R_O + R_G)$, μ is Poisson's ratio and β is the gauge specific transverse sensitivity, then each gauge will have an output voltage proportional to the stress in the direction corresponding to the particular gauge orientation. When the gauge and matching resistor have values of 500 ohms each, Z_C becomes approximately equal to 700 ohms for representative conditions of μ and β equal to 0.28 and 0.02 respectively.

Instruments and Their Selection

As the signal is measured in terms of microinches per inch it will be readily apparent that the voltages available from low resistance gauge circuits must be small, usually less than 100 millivolts. A structure may be stressed at zero frequency, (static loading), or may be a resonant member vibrating at frequencies of several thousand cycles per second, or be subject to shock loading. Sensitive measuring equipment consequently must be selected, keeping in mind the frequencies to be encountered. Vacuum tube equipment usually is required although static and slowly varying strains are measured successfully with d-c microammeters and light-beam galvanometers. Generally, in a stress survey, a number of points must be examined and correlated with one another with respect to time or other variables. Multichannel amplifier recording oscillograph combinations prove most useful in obtaining and preserving this data for later analysis. Figure 6 shows a typical 12-channel oscillograph with 12 channels of amplifiers (three banks of four), a-c power supply, switching panel, and calibrator. For flight work the a-c power supply is replaced with a battery-powered unit.

The instruments can be chosen properly only by an honest evaluation of the response required. This implies the determination of the minimum acceptable gain and the choice of f_{min} and f_{max}, the extreme values of signal frequency which must be transmitted and between which the amplitude-frequency response must be "flat" within, say, $\pm p$ per cent. In general there will be other frequencies, f_1 and f_2, between which the phase distortion must not deviate from a linear function of frequency within some prescribed limit. Then there will be the decision upon indicating or recording instruments, and if recording, whether automatic or attended. If accuracy is very important, some null-balancing arrangement usually is indicated, though such equipment ordinarily will have but a very poor amplitude-frequency response, particularly if manual balancing is used. Generally it will be found that phase response can be improved at the expense of amplitude response and conversely. For instance, a galvanometer element with about 0.6 critical damping will exhibit a flat amplitude response to a higher frequency than it will for any other value of damping, but the phase-frequency characteristic will deviate from linearity at a lower frequency than when the damping is lower than 0.6 critical. This is a difficult choice, for phase relations in the complex stress wave are important if peak values are not to be distorted beyond the specified p per cent. To demand perfect phase and amplitude response (good square-wave characteristic) may mean using quite a different instrument. Once the response characteristics have been fixed—the least requirements for acceptable results—the size, weight, and cost of the equipment can be estimated. A very rough indication of the type of instrument required may be obtained by dividing the instruments into six classes, each one decade apart in the frequency spectrum, as shown in Table I.

Table I. Instruments Classed by Frequency Response

Nominal Frequency Spectrum (Cycles per Second)	Instruments
0–0.2	Indicating instruments and manually balanced null devices (manual recording)
0–2.0	Automatic null-balance recorders
0–20	Direct-coupled galvanometers (no amplification)
2–200	Amplifier-galvanometer combinations (magnetic damping of galvanometers, or piezo-crystal galvanometers)
2–2,000	Amplifier-galvanometer combinations (oil-damped galvanometers)
2–20,000	Amplifier-oscilloscope (cathode-ray) combinations

Static and dynamic strains may be recorded simultaneously by using carrier current excitation or d-c excitation to the bridge circuits and associated recording equipment. The former method is more complex in that it requires a high-frequency source and freedom from variational reactive components in the bridge (which in turn requires phase balancing and probably a phase-sensitive demodulator-filter arrangement). Excitation from a d-c source requires that those components of signal frequency not passed by the amplifier be recorded by some other means. A very satisfactory method which may be used with conventional amplifier-oscillograph equipment has been termed the "insertion" system,[14] whereby the signal is short-circuited cyclically. If the wave form and frequency of the switching action are chosen properly the recorder passes the zero signal pulses, thereby establishing the axis of zero signal on the recording medium. The pulse height is exactly equal to the instantaneous value of the signal, which fact sometimes is used in the exact reduction of the data. Such a system has been in use for over a year in the measurement of steady and transient strains in aircraft propellers.

The choice of instruments will be influenced by the required accuracy, particularly with respect to ambient conditions of temperature, pressure, humidity, mechanical vibration and noise, and power supply variation. Ordinarily, characteristics of the equipment may be specified so that these variables will be of little consequence but oftentimes it becomes desirable to use an instrument under conditions for which it was not intended. Variations in temperature affect the operation of oil and electrolytic capacitors, the response of oil-damped galvanometers, and the lubrication of moving parts in oscillographic equipment. Pressure and humidity affect the operation of slip ring brush combinations in oscillograph motors and transfer equipment (such as is required for aircraft propeller testing). Amplifiers often are subject to disturbance from noise or vibration or both. It even has been the experience of the authors that the severe vibration present on aircraft engine nose sections is sufficient to produce a signal comparable in wave form and amplitude to that of a stress signal, merely due to piezoelectric or electrostrictive effects on certain laminated plastic insulating materials used in the slip-ring assembly and brush rigging. This first was discovered during a check run with the excitation battery disconnected; it subsequently was eliminated by discontinuing the use of these laminated plastics as structural members in the transfer equipment and by other design changes.

When the records are analyzed there remain a few more sources of error and uncertainties. In a complex vibratory

Linear Couplers, Field Tests and Experience at York and Middletown, Pa.

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THE system of bus protection using linear couplers, or air-core mutual reactors, in place of current transformers was described before the Institute in January 1942.[1] By special design the mutual reactors were made astatic or insensitive to outside fields. Through the use of air core the troublesome problem of saturation of iron by the d-c transient component of short-circuit current was eliminated. At the same time adequate energy was derived for decisive relay operation. The coupler secondaries were connected in a series loop including the relay to form a bus protective system.

Several applications of this system have been made now, and it is the purpose of this paper to describe the field tests and subsequent performance of the pioneer applications at the York and Middletown Pa., stations of the Metropolitan Edison Company. Following an analysis of the field tests, which more firmly establish the operating limits of the system, the proposed field of application will be defined in relation to other bus protective systems.

The advantages of bus protection in clearing faults rapidly from a system are well recognized by the industry, and the provision of relay protection for major station busses has been standard practice for a number of years. The problems involved in such protection also are quite well known. One of the principal ones is the saturation of current transformers by the d-c transient component of the short-circuit current. In severe cases the d-c transient component may require 100 times as much flux capacity in the current transformer as is required by the a-c component to prevent saturation completely. The theory of this problem was presented before the Institute by Langguth and Marshall in 1929.[2]

Solutions

There were a number of successful solutions to the problem and it will be necessary to mention a few of these to illustrate the proper field of application of the linear coupler system in relation thereto.

First was the use of large current transformers which would not be saturated by the d-c component. These were used with low resistance leads to minimize the current transformer requirements in this respect. A formula was advanced specifying the requirement of iron cross-section, turns, and lead resistance for nonsaturation, as a function of the fault current and the d-c transient time constant. This was a "bull-by-the-horns" solution and its size, weight, and cost could be afforded only in the most important installations. However, it provided the possibility of instantaneous tripping without any time delay.

A method[3] was developed for calculating, with reasonable engineering accuracy, the time to saturate with off-set currents, and the time and current settings required to prevent misoperation with time-delay overcurrent relays and usual current transformers. However, the time delays required were frequently so long as to point the need of a better solution.

Relays[4] also were developed which would not operate falsely even when used with normal sized current transformers which saturated due to the d-c component. These are multirestraint relays; however, their success is due also to exploitation of variable percentage

Paper 46-36, recommended by the AIEE committee on protective devices, power transmission and distribution for presentation at the AIEE winter convention, New York, N. Y., January 21-25, 1946. Manuscript submitted November 19, 1945; made available for printing December 17, 1945.

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stress wave it should be proper to consider only those stress reversals which occur often enough to be considered dangerous in the life of the tested part, but this is a matter on which it is impossible to be exact.

Conclusions

The quantity and complexity of electrical stress measurements have grown to such an extent that a relatively small part of the whole stress problem may require the full time of one or more individuals. This trend toward specialization naturally reduces the possibility of any one person appreciating the problem as a whole, with the result that one or two aspects may be emphasized while another of equal importance may be neglected. This situation, as discussed in the paper, is exemplified by a precise electrical measurement of a stress which may be subject to appreciable uncertainty in itself (due, say, to neutral axis error) or may be unrepresentative (gauge location in error), so that the responsibility for the procurement of results which depend upon many variables is evident. Although it has been possible to touch but lightly on most of these phases of the measurement problem, it is hoped that the broader consideration of stress determination, as herein presented, will prove helpful to those presently engaged in or who will enter this field.

References

1. THE DEVELOPMENT OF ELECTRICAL STRAIN GAGES, A. V. deForest, H. Leaderman. National Advisory Committee for Aeronautics Technical Note 744, January 1940.

2. United States Patent 2,292,549, MATERIALS TESTING APPARATUS, Edward E. Simmons. August 11, 1942.

3. THE EXTREME PROPERTIES OF MATTER, Sir Charles Darwin. *Engineering*, volume 155, February 5, 12, 19, 1943, pages 105, 106, 136, 137, and 144.

4. MECHANICAL PROPERTIES OF MATERIALS AND DESIGN (book), Joseph Marin. McGraw-Hill Book Company, New York, N. Y., 1942. Chapters 1-4.

5. PHOTOELASTICITY (book), M. M. Frocht. John Wiley and Sons, Inc., New York, N. Y., 1941. Volume 1, chapter 1.

6. THE DYADIC GAGE, Sidney B. Williams. *Proceedings* of the Society for Experimental Stress Analysis, volume 1, number 2, 1944, pages 43-55.

7. ELECTRIC GAGING METHODS, H. C. Roberts. *Instruments*, volume 17, number 6, through volume 18, number 10, 1944-1945.

8. TREATISE ON PHOTOELASTICITY (book), E. G. Coker, L. N. G. Filon. Cambridge Press, 1930.

9. PRACTICAL STRAIN ANALYSIS BY USE OF BRITTLE COATINGS, Greer Ellis. *Proceedings* of the Society for Experimental Stress Analysis, volume 1, number 1, 1943, pages 46-53.

10. Reference 4, chapter 8.

11. Papers presented at Society for Experimental Stress Analysis symposium (May 1944) on residual stresses, C. S. Barrett and others. *Proceedings* of the Society for Experimental Stress Analysis, volume 2, number 1, 1944, pages 147-225.

12. ELECTROMECHANICAL TRANSDUCERS AND WAVE FILTERS (book), Warren P. Mason. D. Van Nostrand, New York, N. Y., 1942. Pages 13-20.

13. RADIO ENGINEER'S HANDBOOK (book), F. E. Terman. McGraw-Hill Book Company, New York, N. Y., 1943. Page 198.

14. MEASUREMENT OF STEADY AND VIBRATORY STRESSES IN AIRCRAFT PROPELLERS, E. F. Shelley. Institute of the Aeronautical Sciences, New York, N. Y., 1946.

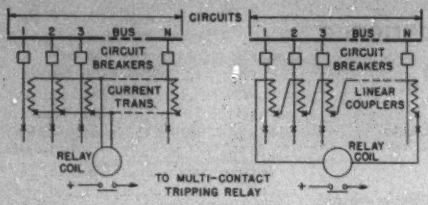


Figure 1. Schematic diagram of differential protection systems

characteristics and the tendency of the d-c component to brake, rather than drive, the induction disk. No small part of this development was the reduction of its operating limits to a few simple rules which insure safe application. This relay provides operation generally in from three to six cycles.

The linear coupler system combines the advantages of high speed and simplicity of the "bull-by-the-horns" method described first, with moderate size and weight of the multirestraint system, and some important advantages of its own. In principle it is the simplest possible system as will be noted (Figure 1b). It is the only system which can be tested at low currents to ascertain for a certainty what its performance will be at high current values. The coupling devices are no larger and often lighter than normal-sized current transformers. They can be mounted in the usual bushing current transformer compartments of circuit breakers. A single relay per phase is required irrespective of the number of circuits involved on the bus, a ground relay being used in addition if ground fault currents are relatively small. Figure 2 illustrates a typical coupler and relay.

The theory of the linear coupler system has been outlined in previous papers.[1,2] Consequently, only a sufficient résumé will be given here to show the significant factors which should be investigated in the field tests.

Résumé of Theory of Linear Couplers

As shown in Figure 1 linear couplers are connected normally in series whereas current transformers are connected in parallel to form a differential protection circuit. The current transformer is designed to produce in its secondary a current proportional to the primary current. As long as there is no bus fault the vector summation of currents in all circuits connected to the bus is equal to zero. Hence the summation of secondary currents, obtained by the parallel connection is likewise zero. In event of a bus fault the current in the relay is proportional to the fault current.

The linear coupler is a mutual reactor and consequently produces in its secondary a *voltage* proportional to the current in its primary. Usually this proportionality is 5 volts secondary per 1,000 amperes primary. If there is no fault on the bus the summation of primary currents is zero and consequently the summation of secondary voltages, obtained by the series connection, is likewise zero. If there is a bus fault the net voltage induced in the coupler-relay loop is proportional to the fault current, that is, 5 volts per 1,000 amperes of fault current in the usual design.

York and Middletown Installations

The first installations of the linear coupler scheme for bus differential protection were made on the Metropolitan Edison Company's system in the new 114-kv, outdoor substations at Middletown and York, each authorized for construction in 1942. Load growth in the York area necessitated conversion to 114 kv of the two 66-kv lines from Middletown to York. The Middletown station provides the interconnection between these two lines and the existing 114-kv circuit to Reading, as well as a principal outlet for the Middletown generation into the general transmission system. The York substation serves as the terminal for the 114-kv lines and the main source of supply into the York area, stepping down through 67,500 kva of transformers.

The Middletown substation is shown in Figure 3. Both substations are identical in basic design, utilizing a compact steel structure, protected by four overhead static wires spaced on 44-foot centers, "back-to-back" circuit bays, and main and transfer strain busses. Each circuit is provided with an oil circuit breaker having 1,500,000 kva interrupting capacity. Three coupling capacitor potential devices are connected to the main bus for relay and synchronizing potential. All secondary cables for control, current (including linear coupler secondaries), potential, power, andl ighting, as well as carrier current concentric cables, are buried directly in the earth in a common trench, between the control room and their respective terminal locations at the outdoor structure. The control and relay panels at Middletown are located about 350 feet distant from the nearest circuit breaker, whereas at York this distance is 200 feet.

A one-line diagram of the six-circuit station at Middletown is shown in Figure 4. An identical 114-kv bus diagram applies for the York station, excepting that there are five circuits instead of six.

The decision to install bus differential protection at these two important substations was made only after long deliberation, including careful analysis of the use of all known differential schemes. The calculated maximum and minimum

Figure 2
(a). Linear coupler
(b). LC-2 linear coupler relay

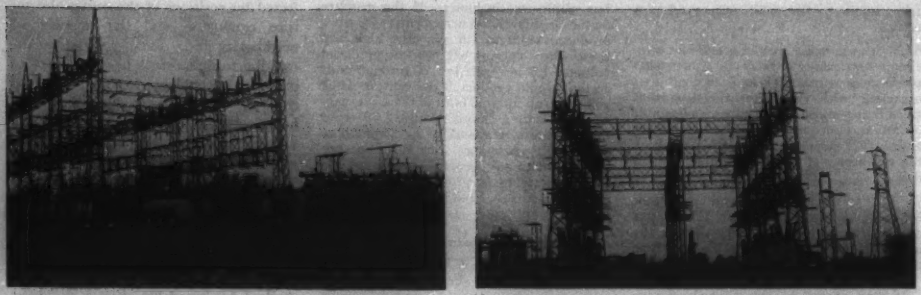


Figure 3. Views of Middletown substation

114-kv bus fault currents for which the relay systems must function were 6,250 and 1,400 amperes respectively at Middletown, and 4,500 and 1,050 amperes respectively at York. All 114-kv transformer banks on this system are wye connected with solidly grounded neutrals, resulting in bus interphase and ground fault currents of approximately equal magnitude. The calculated d-c time constant at Middletown was 0.12 second, and at York 0.06 second.

Conventional Methods Analyzed

Conventional methods, using standard bushing type current transformers in the 115-kv circuit breakers, with paralleled secondary connections, were given first consideration. The "bull-by-the-horns" method was, of course, economically impractical. The method using time delay overcurrent relays appeared unfavorable, as high-speed operation was necessarily sacrificed through provision of sufficient time delay to overcome the effects of d-c saturation in the current transformer. Calculations indicated that the intentional time delay required to permit offset transient recovery would result in relay times ranging from 7 to 60 cycles, under maximum to minimum fault currents, respectively. In addition to extending damage such times would adversely affect the co-ordination with transmission line protection.

The "multi-restraint relay" type of bus protection[4] was found applicable, and under the fault conditions previously stated would result in relay times ranging from 3 to 5 cycles. The number of circuits involved, however, required that two relays per phase be installed at each station. The current transformer connections and relay wiring would be arranged so as to maintain restraint on at least one relay per phase under all through-fault conditions. Since in general two relays per phase provide protection for up to seven source circuits per bus, the addition of main circuits at Middletown might have presented a problem.

A safe application of either of the foregoing systems requires consideration of maximum and minimum fault currents and their distribution, relay and lead burden, ratios and iron cross sections of current transformers, number of generating sources, and d-c time constant, together with other pertinent operating conditions. Since the total burden on the current transformers is an important factor in the successful application of the previously described methods, it follows that the size of conductor used in the secondary cable from the current transformer to the relay may have to be increased as the distance between them is increased.

Linear Couplers Selected

Laboratory tests of the linear coupler scheme previously described offered conclusive evidence that a simple, high-speed bus differential relay system had been developed which was free from all of the inherent problems associated with conventional current-transformer methods. While the linear coupler relay is of necessity a low energy device, any fear that unwanted operations might occur from induced potentials in the secondary cable was believed groundless. Calculations had indicated that such potentials would be very small compared with operating voltages if a continuous secondary loop circuit was provided for each phase, with the outgoing and incoming conductors in a common spiraled cable throughout. Thus, any tendency for induced potentials to appear in the coupler loop would be cancelled. This was proved in field tests at York, to be described later.

Linear coupler bus protection was therefore installed at Middletown and York substations for the following reasons:

1. Simplicity. No calculations were required other than maximum and minimum bus fault curredts and the relay setting for the desired pick-up. Sound fundamental theory of operation had been substantiated by the manufacturer with exhaustive laboratory tests.

2. Linear characteristics of couplers for all values and types of fault current meant freedom from fear of saturation effects caused by offset transients.

3. Faster relay operation (1 to 2 cycles) would be obtained through complete range of fault currents, with only one comparatively simple relay per phase, regardless of the number of circuits connected to the bus. Thus, no complex relay and current transformer secondary connections, and less switchboard space would be required.

4. A complete system required only one secondary cable consisting of six, number 10 copper conductors, running from the relay panel to the first circuit breaker, thence to the second, third, and so on until the loop is completed in the last breaker (Figure 4). Actually, a smaller size conductor can be used, depending entirely upon the desired mechanical factor of safety. A considerable reduction in secondary cable was realized with the linear coupler scheme. For example, at Middletown a total of 2,800 feet of 4-conductor cable would have been required with the multi-restraint relay scheme. For the linear coupler installation a total of 775 feet of 6-conductor cable was installed. Therefore, for the installations under discussion, the latter scheme required approximately 41 per cent of the conductor-feet, that would have been required by the former.

5. If a cable duct system is used the amount of main duct run space saved with the linear coupler scheme is the total number of circuits involved, minus one. This also applies for future circuit additions, in which case the new circuit breaker is connected into the coupler loop by simply extending a 6-conductor cable from the nearest existing breaker, plus a few feet of wire on the relay panel to connect the added breaker

trip circuit to the multicontact tripping relay.

6. With the linear coupler scheme an open circuited secondary or relay coil renders that phase inoperative, whereas such conditions occurring with the conventional current transformer schemes may cause undesirable operation sooner or later. Either manual or automatic equipment is available to check the continuity of the relay-coupler loop if desired.

7. Cost of linear couplers and relays (not including savings in secondary cables) was competitive on new installations with the multirestraint scheme using bushing type current transformers.

It is of interest to note that the 6-conductor secondary cables for both installations were installed in the same trench with all other control and secondary cables leaving the relay panel, being buried directly in the earth over the greater part of the distance to the circuit breakers. Standard 600-volt, nonleaded, unshielded "mummy finish" spiral cable was used.

Field Tests

For a successful linear coupler system which will always trip when desired for internal faults and never trip when undesired as for external faults, the following requirement must be met.

The mutual reactance, or proportionality between secondary voltage and primary current must be the same for all couplers on a bus within certain limits. If the couplers on the circuits where current entered the bus produced voltages 1.5 per cent high and those where current left the bus produced voltages 1.5 per cent low, a through-fault current would produce 3 per cent as much voltage as an internal fault of the same magnitude. Thus a through fault of 33 times the relay setting would be just enough to cause faulty tripping. The tolerance can be reduced to any desired amount but the cost is increased in proportion because of the refinements required in manufacture and testing.

Analysis and measurement of samples had indicated that a tolerance of ±1.5 per cent could be held quite readily. This tolerance includes several sources of variation which will be discussed briefly.

Linear couplers are wound in the form of a toroid similar to a bushing current transformer with a uniformly distributed winding. The core is of course nonmagnetic. This form of coil has theoretically zero mutual reactance to any conductor not linking the toroid and a constant mutual to any conductor which does link it irrespective of its position within the opening. Also its mutual theoretically is unaffected by any external magnetic fields. There are, of course, minor variations due to irregularities of winding so that the mutual is slightly affected by positions of the center and return conductor, and the presence of neighboring iron. Further variations occur due to finite steps of adjustment of individual couplers to the standard coupler. These effects have been exhaustively studied and reported previously[1] and are all included in the ±1.5 per cent over-all tolerance.

In the case of the York and Middletown installations most of the couplers were supplied separate from the circuit breakers, and were mounted in the usual bushing current transformer housings of the breakers in the field. Polarities were checked by impulsing with a flashlight battery as for current transformers. However, the field tests provided an overall check of the tolerance as described above including position effects within the circuit breaker, effect of the iron cases, leads, and coupling with other phases if any. Provision of adequate energy for operation at the proposed relay setting had been demonstrated in the prior laboratory tests of the scheme and therefore merely was confirmed by the field tests.

Tests for accuracy and performance of a linear coupler differential are extremely simple because the d-c component in a

Figure 4 (below). One-line diagram of Middletown substation

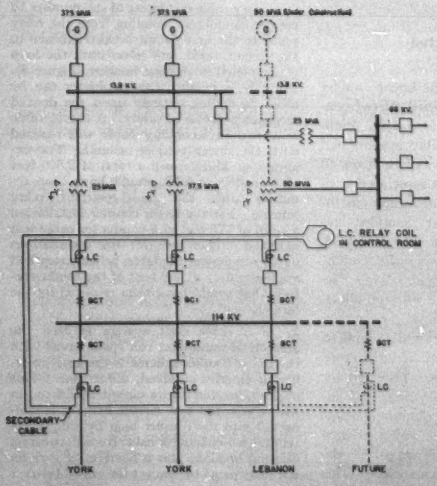


Figure 5 (right). Current-voltage relations in relay-coupler loop

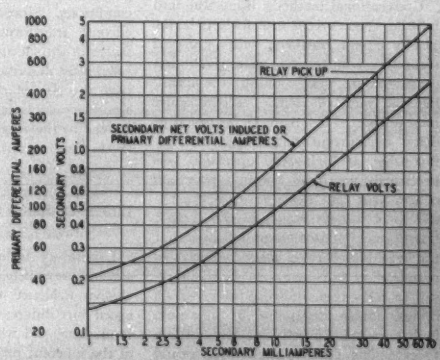
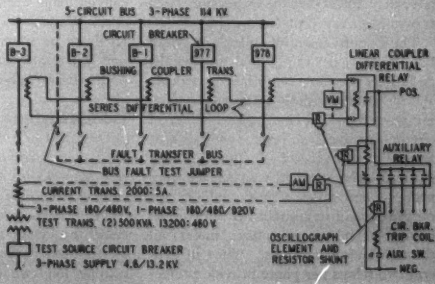


Figure 6 (lower right). Diagram of test connections



fault current has a negligible effect, and the secondary induced voltage is strictly linear with respect to the primary a-c component magnitude. Hence measurements may be made with primary currents just sufficient to give accurate readings on a secondary circuit voltmeter. An electronic voltmeter is ideally suited for reading these low voltages as it has very high impedance so as not to disturb the current flow in the differential circuit.

Methods of Measuring Differential Error

Measurements of differential error are made most directly by opening the series differential loop and measuring the net induced voltage for a through primary current passing into and from the bus. The per cent differential error is then 100 times the net induced volts divided by the secondary voltage of five volts per thousand amperes of through-fault current. Differential error also may be determined with the secondary circuit closed so as to permit normal relay operation by measuring either the voltage across the relay or the secondary current. Either of these measurements are readily translated to net induced volts by a curve (Figure 5). This curve is obtained by applying a voltage in the coupler-relay loop while all primary circuits are open, and reading total volts, relay volts, and secondary current. The operating point of the relay should be definitely noted and indicated on this curve. Tests of this type were made at both Middletown and York. In addition some oscillograms were taken at York for record purposes.

Test Facilities at York and Middletown

Test arrangements at York are shown schematically in Figure 6 and, those at Middletown were similar except that the bus has six circuits and only one 500-kva transformer was available as a test supply. The two test transformers at York permitted tests for all types of faults and a wider range of fault currents. For 3-phase faults the transformers were connected open delta. For heavy-current single-phase faults, phase-to-phase or phase-to-ground, the transformer primaries were connected in parallel and their secondaries in series. The regular high-voltage disconnect switches and transfer bus facilitated selection of the primary circuits to be used during a test. One high voltage circuit was considered the incoming circuit and each of the other circuits in turn were used as outgoing circuits to determine their percentage differential error and to check proper phasing and polarity.

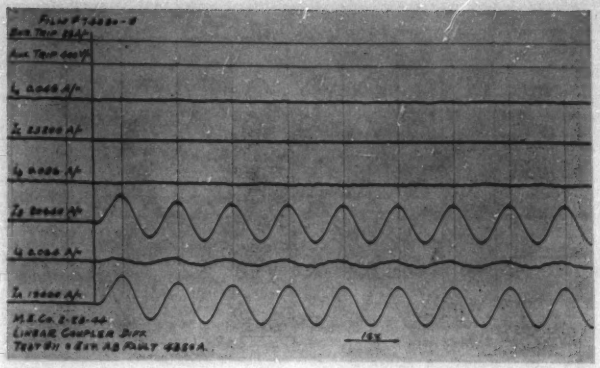


Figure 7. Oscillogram of an external phase-to-phase *AB* fault of 4,850 amperes using relay setting of 550 amperes

Reading from the bottom up the traces are:
I_A —Phase *A* primary current. It shows 4,850 amperes a-c component and a large rapidly decaying d-c transient
i_a —Phase *A* secondary differential error current. It shows 2.5 milliamperes representing 1.3 per cent error
I_B —Phase *B* primary current. It shows same as for phase *A*
i_b —Phase *B* secondary differential error current. It shows negligible error
I_C —Phase C primary current. It shows zero current
i_c —Phase C secondary differential error current. It shows no induction from the fault current
Aux. trip—Voltage across auxiliary tripping relay coil. It shows that the differential relays did not close their contacts
Bkr. trip—Current through *B*-3 circuit breaker trip coil. It shows that it was not tripped

Results of Tests

The highest differential error measured between any two couplers was found to be 2.1 per cent at York and 2.6 per cent at Middletown. The average of such differential errors was about 0.75 per cent. As maximum capacity through faults involve more than one incoming circuit and may involve more than one outgoing circuit, the actual differential error depends upon the fault current distribution through the various couplers and their individual errors. This would be less than the highest per cent differential error between any two couplers, but by assuming it to be the same an additional factor of safety is included against operation for through faults.

External Fault Oscillogram

Figure 7 shows an oscillogram for an external *AB* phase-to-phase fault of 4,850 amperes fed through circuit breakers *B*-3 and 977. The relays were set to pick up for a 550 ampere bus fault, or 11.3 per cent of this through fault current, and did not operate as the differential error was less than the relay setting. The oscillogram shows the fault currents I_A and I_B initially offset, negligible i_b differential current in the *B* phase loop, and 2.5 milliamperes i_a differential in the *A* phase loop. From Figure 5 this 2.5 milliamperes indicates 0.318 volt net was induced in the loop and this in turn represents 1.31 per cent differential error. During this test the *A* phase relay voltage was read as 0.15 volt indicating 1.27 per cent differential error, and the *B* phase relay voltage was read as 0.05 volt indicating 0.203 per cent differential error. A further check of these differential errors was obtained more precisely in a steady-state test for an external 3-phase fault of 1,075 amperes by reading the net induced voltages directly with the differential loops open; and it gave differential errors of 1.30 per cent for phase *A*, 0.208 per cent for phase *B*, and 0.524 per cent for phase *C*. With 1.3 per cent differential error and a relay set to pick up for a 550 ampere bus fault, a through fault current of over 42,000 amperes would be required to cause undesired tripping.

Internal Fault Oscillogram

Figure 8 shows an oscillogram for a 3-phase bus fault of 1,157 amperes repre-

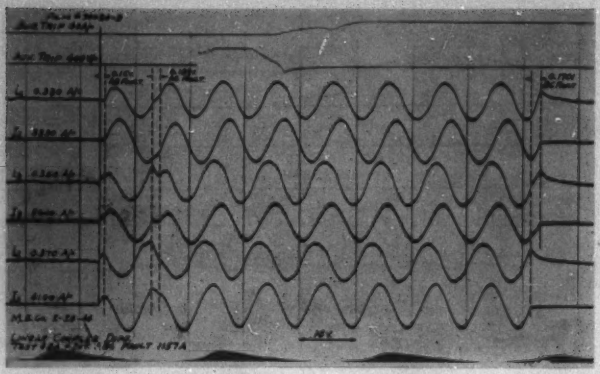


Figure 8. Oscillogram of an internal 3-phase fault of 1,157 amperes (average of 3 phases) using relay settings of 550 primary amperes, 36 milliamperes secondary current

Reading from the bottom up the traces are:
I_A—Phase *A* primary current. It shows 1,120 amperes
i_a—Phase *A* secondary differential current. It shows 87 milliamperes
I_B—Phase *B* primary current. It shows 1,310 amperes
i_b—Phase *B* secondary differential current. It shows 95 milliamperes
I_C—Phase C primary current. It shows 1,040 amperes
i_c—Phase C secondary differential current. It shows 76 milliamperes
Aux. Trip—Voltage across auxiliary tripping relay coil. It shows that the differential relays closed their contacts in 1.75 cycles
Bkr. Trip—Current through B-3 circuit breaker trip coil. It shows it was energized 3.13 cycles after inception of fault

senting 2.1 times the 550 ampere pick-up of the relays. It shows that the linear coupler relays energized the auxiliary trip relay in 1.75 cycles, the auxiliary trip relay energized the breaker trip coil at 3.13 cycles, and the fault was cleared at 8 cycles. This 3-phase fault was unusual in that it changed to different types of interphase faults because the test source voltage of 160 volts was not sufficient to establish or maintain arcs under oil with minute separation of the breaker contacts. The fault was successively an *AB* fault for 0.10 cycle, an *ABC* fault for about a cycle, an *AC* fault for 0.15 cycle, an *ABC* fault until the breaker started to interrupt and ended as a *BC* fault for the final 0.17 cycle. These fault transients did not interfere with operation of the relays as each showed a target, indicating all three relays closed their contacts within a 1/4 cycle period, required for the first trip circuit to be sealed. This test was a repeat of the previous test made without oscillograph and with the relay trip circuit disconnected so that the fault could be held long enough to read the three primary currents and the three relay voltages. These readings verified each other and the subsequent oscillographic record.

Summary of York Tests

These two oscillograms and their explanations are representative of the series of 19 fault tests made on the 114-kv circuits at York. They included 3-phase, phase-to-phase, and phase-to-ground faults both external and internal. The phase-to-ground faults were made through the structural steel and its multiple paths lowered the impedance to give fault currents up to 6,500 amperes. This current for a bus fault reduced the relay time to 1.33 cycles. The ground fault tests showed a neglible induction effect in the unfaulted phase loop circuits. In addition to the fault tests made on the 114-kv circuits, a ground fault was applied to a lighting circuit installed in the same trench as the bus differential leads to the structure and it was found that the 250 amperes that flowed out on the lighting circuit to return by way of ground induced quite negligible voltages, 0.012 volt, in the bus differential loops. This is less than half of one per cent of that necessary to operate the relays with the settings used.

Middletown Tests

The Middletown tests were similar but were made without oscillograph and with only one single-phase test transformer, which was able to deliver up to 4,800 amperes for a through fault. So as to demonstrate better the reliability of the linear coupler differential, the relay setting was deliberately lowered from the contemplated 700 ampere setting to 150 amperes, representing 3.1 per cent of the 4,800 ampere maximum through fault test. A complete round of 32 tests were made with this sensitive setting. The relays operated for all bus faults and did not operate for any external faults, even though differential errors up to 2.6 per cent were measured. After this the relays were returned to their normal 700 ampere pickup setting and then their complete tripping operation was demonstrated with bus faults of about 1,100 amperes.

Operating Experience

Field experience must be depended upon to show up any factors which may have been overlooked, and constancy of performance over a period of time, and to bring out any problems of maintenance or adjustment that may be involved.

Based on minimum fault current of 1,400 amperes and 1,050 amperes at Middletown and York, respectively, the linear coupler relays were set at a pick-up value of 700 amperes and 550 amperes, respectively. They have been in service approximately two years, and although during this period there have been no bus faults at either location to require operation, there have been a total of 8 faults on the Middletown-York circuits and 35 faults on the Middletown-Lebanon circuit, none of which caused incorrect operation.

A 66-kv ground fault on the 50,000 kva transformer bus structure at Middletown likewise did not cause operation of the linear coupler relays although the linear coupler secondary cable is buried in the earth in close proximity to the fault location.

Conclusions

In addition to providing assurance that the York and Middletown bus protection systems are in first class operating conditions, the tests have established the following facts of importance in general application of the system.

1. Linear couplers can be factory tested separately from the circuit breakers and then mounted in the breakers in the field, without any special adjustments.

2. The factory tolerances being maintained on the coupler mutual reactance results in over-all variations after mounting not over ±1.5 per cent.

3. With normal precautions of keeping the wires of the coupler-relay loop in a common

spiraled cable, induction from other circuits in the control duets is negligible.

4. Field tests confirm that significant tests can be made at reduced primary currents. The system is linear and the percentage errors so determined apply equally well at higher currents. This facility is not enjoyed by any other system.

In many applications the choice lies between the multirestraint relay with current transformers and the linear-coupler system. If the current transformers already exist and are usable as they are or with rewinding, there may be an economic factor in favor of the multirestraint relay. However, this must be balanced against the lower cost of secondary cable installation with the linear couplers. Also, if partial differential feeder-backup protection is to be applied using the same current transformers, the corresponding equipment has not yet been developed for application with the couplers. The 3- to 6-cycle operating time of the multirestraint relay system has usually proved adequate from a stability standpoint.

On new installations or revamping projects where either current transformers or couplers will need to be procured, the linear coupler system offers instantaneous tripping in a very simple system which can be readily applied and tested. Its cost is competitive with the multirestraint relay system.

The multirestraint relay is applicable when the current range from maximum through fault to relay setting is up to 100 to 1. One relay per phase suffices with up to three major sources (generators, transformers, bus-ties) per bus sections; two per phase for up to seven major sources.

With the linear coupler system but one relay per phase is used irrespective of the number of circuits connected to the bus. However, energy requirements fix the lower limit of relay setting for positive action at approximately 300 amperes with six circuits per bus, plus 25 amperes per additional circuit. The range of currents from maximum through fault to relay setting has been limited purposely to 17 to 1. As demonstrated by these tests this limit is quite conservative in the case of the installations described. This range usually covers the required range for phase currents and also for ground currents on solidly grounded systems. Where ground currents are limited as by grounding resistors, making the over-all current range more than 17 to 1, a separate ground relay is required in the linear coupler system and is prevented from operating for other than single-line-to-ground faults by a ground detector relay described by Sonnemann.[6] The ground current setting cannot be below the 300 amperes for a 6-circuit bus plus 25 amperes per additional circuit.

Summarizing, local conditions will frequently dictate the proper application. Where high speed, simplicity and reliability are important, the linear coupler system should receive prime consideration.

References

1. Linear Couplers for Bus Protection, E. L. Harder, E. H. Klemmer, W. K. Sonnemann, and F. C. Wentz. AIEE Transactions, volume 61, 1942, May section, pages 241–8.

2. Current Transformer Excitation Under Transient Conditions, D. E. Marshall, P. O. Langguth. AIEE Transactions, volume 48, 1929, pages 1464–74.

3. Current Transformers and Relays for High Speed Differential Protection, With Particular Reference to Offset Transient Currents, E. C. Wentz, W. K. Sonnemann. AIEE Transactions, volume 59, 1940, August section, pages 481–8; discussion pages 1144–8.

4. Considerations in Applying Ratio Differential Relays for Bus Protection, R. M. Smith, W. K. Sonnemann, G. B. Dodds. AIEE Transactions, volume 58, 1939, June section, pages 243–52.

5. Air Core Couplers Simplify Bus Protection, E. L. Harder. *Westinghouse Engineer*, May 1942, page 43.

6. A New Single-Phase-to-Ground Fault-Detecting Relay, W. K. Sonnemann. AIEE Transactions, volume 61, 1942, September section, pages 677–80; discussion pages 995–6.

Long 60-Cycle Arcs in Air

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Synopsis: Volt-ampere characteristics of 60-cycle arcs in still air with lengths and currents such as occur in power systems have been investigated under laboratory conditions. The arcs varied in peak current from 68 to 21,750 amperes and in length from 1/8 to 48 inches. Typical oscillograms and volt-ampere curves of these tests are presented. The voltage gradient in the arc is affected very little by current magnitude. Throughout the entire range all gradients remained between 21.5 and 50 volts per inch, with 35 per cent of all values in a 5 volt per inch interval having an average value of 34 volts per inch. The increase in apparent gradient due to voltage drop at the electrodes was found to be negligible where the arc length exceeds several feet. The decrease in short-circuit current of a power system through a series arc as compared with that for the same system with a metallic short circuit has been investigated. Data are presented showing the actual reductions observed for various conditions of circuit voltage and impedance.

SHORT CIRCUITS on transmission lines and at terminals of high voltage power apparatus practically always take place through long arcs in air. It is important, therefore, to know to what extent these arcs limit the short-circuit current and make it less than would occur with a metallic short circuit. The drop across the arc also affects the phase angle between voltage and current in directional types of relays. The data in the form presented here also can be used to indicate the current limiting effect of arcs on low voltage circuits. Although considerable data from field studies of transmission line flashovers are available,[1,2] the uncontrolled conditions do not permit any accurate determination of the arc characteristics of the arcs in the flashovers.

This investigation, therefore, has been carried out under laboratory conditions where better control of the variable factors is possible.

Testing Procedure and Apparatus

In order to cover a wide range of current values the 27,000-kva single-phase transformers in the Westinghouse high voltage laboratory at Trafford, Pa., were used to supply power for these tests. The current was limited by the impedance of the transformers and reactors connected in series.

Arcs varying in length from 1/8 to 48 inches and in peak current from 68 to 21,750 amperes were investigated. Most of these tests were made with brass electrodes at 48 inches separation. This large electrode separation was chosen so that the voltage drop adjacent to the electrodes would be negligibly small. However, owing to the limited capacity of the transformer bank, for currents in excess of 10,000 amperes the transformers had to be reconnected for smaller voltage. This voltage was insufficient to maintain the current in the 48-inch arc. For this reason these tests were made at 24-inch and 12-inch contact separations.

The arcs, which were initiated by means of fuse wires, were drawn in a vertical

Paper 46-22, recommended by the AIEE committee on protective devices and presented at the AIEE winter convention, New York, N. Y., January 21–25, 1946. Manuscript submitted November 20, 1945; made available for preprinting December 13, 1945.

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Table I. Arc Volts Per Inch at Peak Current on Long 60-Cycle Arcs in Air

Test	Arc Length, Inches	Peak Arc Currents Each Half Cycle							Arc Volts Per Inch on Each Half Cycle						
		1	2	3	4	5	6	7	1	2	3	4	5	6	7
A	48	140	145	134	136	135	137	125	25	27	31	40	35	38	27
B	48	68.5	130	109					27	21.5	21.5				
C	48	260	238	236	192				25	30	30	30			
D	48	544	445	500	435	405			32	29	32	32	31		
E	48	396	322	337	330	300			26	31	33	40	36		
F	48	1,460	1,340	1,385	1,290	1,385	1,380	1,240	38	35	31.5	44	32	27	30
G	48	2,500	2,680	2,630	2,680	2,630	2,480	2,525	35.5	30	30	26	28	28	27
H	48	1,010	1,675	1,820	1,920	1,780	1,410		35	27	30	26	29	29	
I	48	708	870	1,535	2,060	3,780			35	37	33	31	30		
J	48	735	2,360	3,540	3,730	3,380			43	30	31	29	30		
K	48	1,135	812						41	36					
L	48	2,100	4,040	6,780	10,000	10,000			43	34	35	30	30		
M	48	8,230							35						
N	48	3,550							35						
O	48	7,750							35						
P	48	6,450	3,225	5,330	6,450	10,150	10,150		40	46	42	43	30	28	
Q	48	2,580	2,420	7,750	9,500	8,550	7,600		40	38	32	34	33	36	
R	48	5,200	7,150	6,660	7,070	6,750	6,660		35	36	36	35	30	28	
S	48	4,370	5,440	5,150	5,100	5,150	4,800		36	31	31	31	31	31	
T	48	4,370	5,400	5,150	5,250	5,250	4,910		34	31	31	27	27	26	
U	48	4,270	5,490	5,000	5,250	4,910			40	34	30	31	34		
V	48	5,400	5,150	5,250	5,250	5,150	4,910		54**	35	31	27	31	32	
W	24	10,000	14,200	11,900	12,250	11,900			35	34	40	38	30		†
X	24	2,010							48						†
Y	24	7,640							47						†
Z	12	6,840	20,500	17,500	18,500	17,700				54	59	59	56		†
AA	12	12,450	19,100	17,500	19,100	14,900			46.3	50.5	59	56	55		*
AB	12	11,700	21,750	21,150	20,000				45	41	41	40			‡
AC	12	10,900	15,100	14,500	14,000	12,500			45	43	39	41	39		‡
AD	12	6,900	8,670	7,950	8,070	7,370			41	34	36.5	40	39		‡
AE	12	7,330	8,200	8,330	7,720				52	47	36.5	42			‡
AF	12	6,990	8,125	7,800	7,650				37	39	38	38			‡
AG	12	7,150	7,970	7,650	7,650	7,550			42	42	43	44	50		‡
AH	12	6,570	8,125	7,800	7,850	7,230			38	43	38	39	43		‡
AI	12	4,770	5,880	5,180	5,180				37	37	37	43			‡
AJ	12	8,550	15,750	14,500	14,500				34	41	41	38			‡
AK	12	10,450	17,700	19,700	19,700				43	43	43	43			‡
AL	0.125	15,750	15,250	15,750	14,900	14,000			(34.8)	(42.6)	(45.2)	(45.2)	(44)		‡, #
AM	0.125	22,100	26,000	25,000	23,200				(42.6)	(64.5)	(86.5)	(90.4)			‡, #
AN	12	13,850	20,900	19,700	21,500	14,000			43	41	46	41	40		‡
AO	12	9,970	15,250	13,300	13,500	11,200			46	47	42	45	45		‡

† Probable bowing of arc.
* Photograph indicates bowing of arc to approximately 1.5 gap length.
‡ Leads to test rearranged. Photograph shows no bowing of arc on *AB*.
# Figures give total arc volts on the ½-inch gap.
** Abnormally high voltage undoubtedly due to its occurrence immediately after fusing of large size fuse wire.

plane to prevent arc elongation by convection. To eliminate as far as possible any looping of the arc, the current leads to the terminals were placed along the longitudinal axis for a distance of 2 to 4 feet. Observations made through dark glasses and also by photography indicate that the arc is reasonably straight between the electrodes when these precautions are taken.

Magnetic oscillograms were taken of all tests, and measurements of current and arc voltage data were made from these records.

Variation of Voltage Gradient in the Arc With Current

Table I summarizes the data for all the arcing tests, giving the peak current and corresponding voltage gradient in the arc for each half cycle of arcing. No correction has been made for potential drop at the electrodes in this table.

Figure 1 shows graphically the variation of voltage gradient in the arc with current, using the data from Table I. A correction of 3 volts per inch was made for electrode drop in plotting the data for the 12-inch long arcs, as this is approximately the proper value indicated by tests which will be discussed further in a later paragraph. Tests *W* to *AA* inclusive were omitted from this curve, as it is believed that there was some arc elongation on these tests due to magnetic fields from the current supply leads.

This curve shows that practically all of the arc voltage gradients found in these tests fall between 25 and 50 volts per inch. The average of the gradients appears to remain constant at 31 to 33 volts per inch for all currents up to 5,000 amperes, rises slowly to 38 volts per inch at 10,000 amperes, and remains constant up to over 20,000 amperes.

The fact that the arc voltage gradients cover a rather wide band has not been entirely explained. It is believed, however, that at least a part of this variation can be accounted for by the effects of magnetic forces moving the arc about. If the

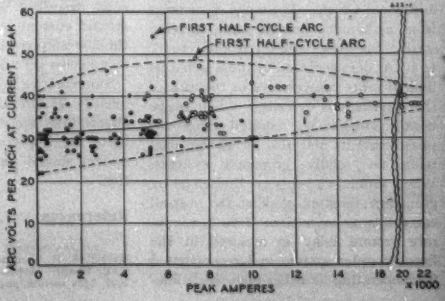

Figure 1. Voltage gradients at peak current on 60-cycle power arcs in air

● 48-inch arcs
○ 12-inch arcs

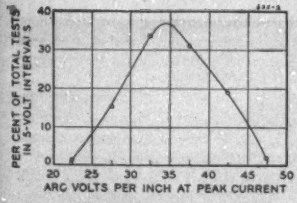

Figure 2. Distribution of voltage gradients at peak current on 153 half cycles of arcing

Peak current range from 68 to 21,750 amperes

arc terminals strike unsymmetrically, or if the axis of the arc moves away from the axis of the electrodes, magnetic forces act to accelerate such motion. This results in slight variations in arc path and relative motion of the arc and surrounding air. The effect of convection air currents and turbulence conditions at the arc boundary change and cause a more rapid loss of heat and ionization requiring higher arc voltage to maintain the current. The 3.7-ampere arc in Figure 11 shows variations in arc path of a substantially

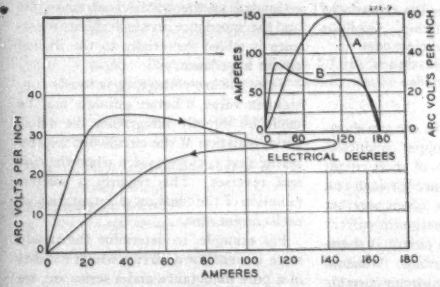

Figure 3. Volt-ampere characteristic for a 100 rms ampere arc

Test *A* of Table I.
Arc length 48 inches
A—Amperes
B—Volts

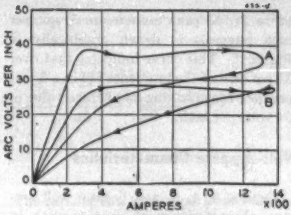

Figure 4. Volt-ampere characteristics of a 1,000 rms ampere arc

Second and sixth half cycles of test *F*, Table I.
Arc length 48 inches
A—Second half cycle
B—Sixth half cycle

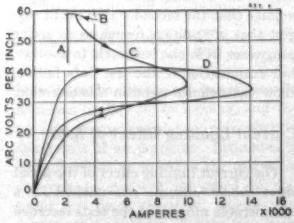

Figure 5. Volt-ampere characteristics of a 10,000 rms ampere arc

First and second half cycles of test *W*, Table I
Arc length 24 inches
A—Fusing current, 2,260 amperes
B—Arc volts at fusing, 178 volts per inch
C—First half cycle
D—Second half cycle

Table II. Current Limiting Effect of Series Arcs on Short-Circuit Currents

Test	No-Arc Short-Circuit Peak Current	Arc Length, Inches	Circuit Volts, Rms	First Half Cycle Arc Current, Per Cent of No-Arc Short-Circuit Current	Maximum Arc Current, Per Cent of No-Arc Short-Circuit Current
A	144	48	5,750	97	100
B	142	48	2,300	47.5	77
C	382	48	2,300	68	68
D	735	48	2,300	74	74
E	360	48	4,600	100	100
F	1,420	48	4,600	100	100
G	2,830	48	4,600	88	95
H	2,830	48	2,300	35	68
I	2,830	48	2,300	25	97
J	5,660	48	2,300	13	66
K	9,900	48	2,300	11.5	11.5*
L	16,600	48	2,300	13.7	60
M	16,600	48	2,300	50	50*
N	16,600	48	2,300	31.5	31.5*
O	16,600	48	2,300	48	48*
P	16,600	48	2,300	39	61
Q	16,600	48	2,300	15.6	57
R	8,150	48	4,600	64	88
S	5,630	48	6,900	77	97
T	5,500	48	6,900	80	98
U	5,450	48	6,900	78	100
V	5,450	48	6,900	99	99
W	16,300	24	2,300	61	87
X	27,300	24	1,150	7.4	7.4*
Y	27,300	24	1,150	28	28*
Z	33,400	12	1,150	20	61
AA	27,300	12	1,150	45	70
AB	27,300	12	1,150	43	80
AC	16,300	12	2,300	67	93
AD	8,100	12	4,600	85	100
AE	8,100	12	4,600	90	100
AF	8,100	12	4,600	86	100
AG	8,100	12	4,600	88	98
AH	8,100	12	4,600	81	100
AI	5,450	12	6,900	88	100
AJ	16,300	12	2,300	52	96
AK	27,300	12	1,150	38	72
AL	16,300	0.125	2,300	97	97
AM	27,300	0.125	1,150	80	95
AN	27,300	12	1,150	47	78
AO	16,300	12	2,300	61	93

* Arc extinguished itself in 1 or 2 half cycles.

straight arc which seem to agree with this explanation.

Two tests in Table I, *AL* and *AM*, were made on 1/8-inch long gaps in order to determine the approximate additional voltage due to drops at the electrodes. The maximum currents on the first half cycles of these tests were respectively 15,750 and 22,100 amperes, and the corresponding arc voltages 34.8 and 42.6 volts. Although a small part of this voltage can be attributed to positive column drop in the 1/8-inch long arc, the results indicate that approximately 30–40 volts can be attributed to drop at the electrodes. The positive column gradient expressed in volts per inch is, therefore, approximately, $(e_a-35)\div l$, where e_a is total arc volts, and l is arc length in inches. This indicates that drop at the electrodes has a negligible effect on the apparent gradient if the arc length exceeds several feet.

The distribution of voltage gradient values for the entire series of tests from

68 to 21,750 peak amperes in 5 volt per inch intervals is shown graphically in Figure 2. This curve indicates that over 35 per cent of the gradients fall in a 5 volt per inch range having an average value of 34 volts per inch.

Volt-Ampere Characteristics

Figures 3, 4, 5, and 6 show volt-ampere characteristics of arcs varying in peak current from 145 to 21,750 amperes. The volt-ampere curves are similar for both high and low currents, but there is considerable variation from one half cycle to another. This is illustrated by the curves of Figure 4 showing two half cycles of a 1,000 rms ampere arc. Here the sixth half cycle is considerably lower in arc voltage than the second. This might suggest that arc voltage decreases as arcing progresses from one half cycle to another, but examination of the test data fails to show any definite trend in this direction.

Current Limiting Effect of Arcs

The current limiting effect of the arc at short-circuit currents was studied for a considerable number of the tests recorded in Table I, by first drawing an arc between a pair of electrodes and then taking the short-circuit current under the same

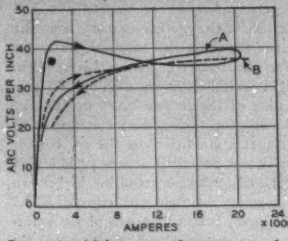

Figure 6. Volt-ampere characteristics of a 15,000 rms ampere arc

Second and fourth half cycles of test *AN*, Table I. Arc length 12 inches. Gradients corrected for drops at electrodes
A—Second half cycle
B—Fourth half cycle

conditions, except with the arc gap short-circuited with a heavy copper conductor.

In Table II the values of short-circuit current without a series arc for each test condition of Table I are given together with the percentage reduction in current observed when the same circuit is short-circuited through a series arc. Nominal values of the no-arc short-circuit currents are given for the tests in which these values were not experimentally observed.

Typical oscillograms are shown in Figures 7 and 8, illustrating the reduction in short-circuit current due to series arcs. These oscillograms show that a 48 inch long arc reduces the current very appreciably on a 4,000-ampere 2,300-volt circuit, but has much less effect at 6,900 volts with approximately the same current. This may be expected, as the arc voltage in the latter case is a much smaller part of the applied circuit volts. As a rough estimate the arc may be treated as a series resistance having a value equal to arc volts divided by normal rms short-circuit amperes. The approximate reduced value of current with a series arc then may be estimated as the quotient of rms volts and the impedance, in which the arc resistance is added vectorially to the normal circuit impedance.

Since the arc voltage, e_a, is nearly constant in value, a better estimate may be made by directly integrating the differential equation of the circuit but remembering that e_a changes sign when the current reverses. This requires a redetermination of the constant of integration at each current zero.

For example, to determine the steady state current for a current which consists of a pure inductance and a series arc, we may start with the equation,

$$A \cos \omega t + B \sin \omega t - L\frac{di}{dt} - e_a = 0 \qquad (1)$$

where

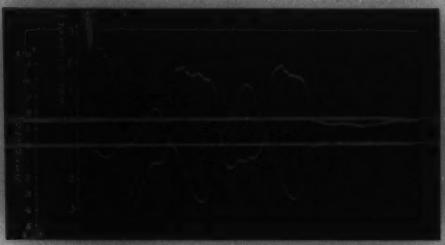

Figure 7 (above). Effect of a series arc in reducing short-circuit current in a 4,000 rms ampere 2,300 rms volt system

A. Current and arc voltage with a 48-inch series arc. Test *J*, Table I. Maximum peak current 3,730 amperes
B. Current in the same circuit without a series arc. Maximum peak current 5,660 amperes

Figure 8 (below). Effect of a series arc in reducing short-circuit current on a 4,000 rms ampere 6,900-volt system

A. Current and arc voltage with a 48-inch series arc. Test *S*, Table I. Maximum peak current 5,440 amperes
B. Current in the same circuit without a series arc. Maximum peak current 5,630 amperes

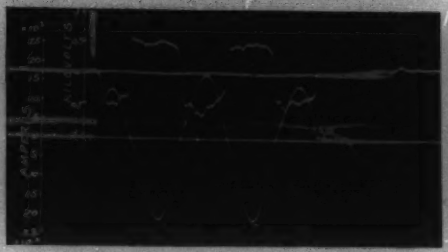

Figure 9 (above). Oscillogram of a short-circuit test on a 20,000 rms ampere, 1,150 rms volt circuit, with a 12-inch series arc

Test *AN*, Table I. Maximum peak current 21,500 amperes

Figure 11 (right). Photograph of a 48-inch 3.7 rms ampere arc showing variations in arc path of a substantially straight arc

$A \cos \omega t + B \sin \omega t$ = sinusoidal impressed voltage

$\sqrt{A^2+B^2} = E_m$ = maximum value of impressed voltage

L = inductance in henrys

e_a = arc voltage (assumed of constant value)

Integrating equation 1 gives

$$i = \frac{A}{\omega L} \sin \omega t - \frac{B}{\omega L} \cos \omega t - \frac{e_a}{L} t + K \qquad (2)$$

Figure 10. Photographs of 12-inch high current arcs showing the effect of the magnetic field due to the supply leads on the shape of the arc

A (below, left). Substantially straight arc when current supply leads are brought in along the axis of the arc. Test *AK*, Table I. Maximum peak current 19,700 amperes

B (below, right). Bowing of the arc when the supply leads are not located along the axis of the arc. Test *AA*, Table I. Maximum peak current 19,100 amperes

The supply leads have been retouched to show their locations more clearly

as long as the current and with it e_a does not change sign.

We now assume that i is initially zero when t is zero and passes through zero again at uniform half cycle intervals. Then the constants K, B, and A may be evaluated as follows:

When $t=0$, $i=0$; substituting these values in equation 2 gives

$$K = \frac{B}{L\omega}$$

When $t = 1/2$ cycle or π/ω, $i=0$; substituting these values in equation 2 gives

$$B = \frac{e_a \pi}{2}$$

$$A = \sqrt{E_m^2 - B^2} = \sqrt{E_m^2 - \left(\frac{e_a \pi}{2}\right)^2}$$

Using these values for A, B, and K in equation 2 gives the solution for the current in terms of known constants as follows:

$$i = \frac{\sqrt{E_m^2 - \left(\frac{e_a \pi}{2}\right)^2}}{\omega L} \sin \omega t - \frac{e_a \pi}{2\omega L} \times \cos \omega t - \frac{e_a}{L} t + \frac{e_a \pi}{2\omega L} \qquad (3)$$

The ratio of this current at peak value to that without the series arc is very nearly

$$\frac{\sqrt{E_m^2 - \left(\frac{e_a \pi}{2}\right)^2}}{E_m} = \sqrt{1 - \left(\frac{e_a \pi}{2E_m}\right)^2}$$

It also may be shown from equation 1 that the current lags the voltage by an angle,

$$\theta = \cos^{-1} \frac{B}{\sqrt{A^2+B^2}} = \cos^{-1} \frac{e_a \pi}{2E_m}$$

In actual faults the arc length usually increases by bowing or looping, and the arc voltage gradient also may rise slightly as a result of air currents. Estimates of current reduction in which the values for arc voltage gradient presented in this paper are used, therefore, should give conservative, that is slightly too high, current values.

Conclusions

1. The average voltage gradients at current peak for 60-cycle arcs in air lie between 31 and 38 volts per inch for currents over the entire range from less than 100 to over 20,000 peak amperes.

2. The arc voltage varies considerably from one half cycle to another. The extreme range of this variation was from 21.5 to 50 volts per inch. Arc voltages on low currents vary over a wider range than on high currents.

3. While the variability of arc voltage has not been explained satisfactorily, it is believed that it is due at least in part to the magnetic forces acting on the arc which tend to shift the arc core into new arc paths that are less highly ionized and require higher arc voltage to maintain the current.

4. The average arc voltage gradient at current peak appears to rise from about 31 volts per inch at currents below 5,000 peak amperes to 38 volts per inch in the 10,000 to 20,000 ampere range.

5. For the complete range of currents from 68.5 to 21,750 peak amperes, 35 per cent of all the arc voltages fall within a 5 volt per inch interval having an average value of 34 volts per inch.

6. The current limiting action of arcs on short-circuit currents depends on the relative value of the total arc voltage to the circuit voltage. Approximations by calculation or graphical means of current reduction resulting from a series arc should be possible

Industrial Application of Rototrol Regulators

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MEMBER AIEE

Synopsis: The Rototrol has been applied in considerable numbers to a wide variety of industrial applications. It has met adequately the need for a simple and reliable regulator which is capable of withstanding the rigors of general industrial usage and which is sufficiently elemental in operation that it can be understood by nontechnical maintenance personnel. It has been accepted enthusiastically by industry, and applications in both existing and new fields are increasing rapidly. This paper discusses the fundamental theory of the Rototrol, the application of the circuits most commonly used, and cites operating results for typical installations.

THE Rototrol is nothing more than a d-c generator similar in design and theory of operation to the standard d-c generator, but with a number of field windings which are designed and connected in various ways, depending on the regulating problem. The Rototrol functions entirely through the interaction of these fields, and has no moving parts or circuits which require delicate adjustment for proper operation or to compensate for wear. After initial adjustment during installation no further attention is required other than the routine maintenance associated with a d-c machine of similar size. The Rototrol is driven at constant speed either by a small squirrel-cage induction motor or as a part of the motor generator set or exciter set of the adjustable voltage drive which it serves.

The Rototrol, as shown in the functional diagram, Figure 1, is one of the most simple regulators yet devised. The principal elements are a self-energizing field (either in series or in parallel with the armature) and the separately excited control fields (usually two in number). One of the control fields commonly is referred to as the pattern field and is excited from a constant potential source. The other control field measures the quantity to be regulated and is referred to as the pilot field. The pattern and pilot fields usually are connected with their ampere turns in opposition, so that the pilot field measures the quantity to be regulated and compares it with the pattern field. Any net difference in these fields will cause the Rototrol to exert corrective forces to reduce the difference, so that the pattern and pilot fields balance out when the quantity under regulation is at the proper value.

Assume for the moment that the self-energizing field is short-circuited. Under this condition the ampere turns required to generate output voltage necessarily must come from the difference in excitation of the pattern and pilot fields. Precise regulation would be impossible, as a change in operating conditions would necessitate a greater or less difference in ampere turns, and the quantity under regulation would vary. From this it is concluded that for high accuracy the pattern and pilot fields must control the Rototrol output without supplying the ampere turns required to generate output voltage. The self-energizing field must perform this function so that the control fields are free for their regulating and forcing functions.

The self-energizing field is designed and tuned by a simple resistor adjustment, so that its resistance line is coincident with the air gap line of the no-load saturation curve. For instance, if 1 ampere in the self-energizing field generates 50 volts across the brushes, and the resistance of the self-energizing field circuit including the Rototrol armature, the self-energizing field, the field of equipment under control, and the tuning resistor is 50 ohms, 50 volts will cause 1 ampere to flow through the circuit. Following this further, if 2 amperes flow in the self-energizing field, 100 volts will be generated which will cause 2 amperes to flow through the tuned or self-energized circuit. With the self-energizing field so designed and adjusted, it is possible for the Rototrol to operate over the straight portion of its saturation curve without the control fields supplying the magnetomotive force necessary to generate voltage. Such a device then may be used as a simple and accurate regulator.

In order for the saturation curve to approximate closely the self-energizing field circuit resistance line, it is necessary to minimize hysteresis effects. By the use of special steels, or by special treatment of standard steels, hysteresis or residual magnetism can be reduced to the point where its effect is negligible. For example, a recent Rototrol on the basis of normal saturation for a d-c generator tested 0.4 per cent residual voltage. A comparable value for the usual d-c machine is 5.0 per cent.

Although the foregoing discussion describes a Rototrol with two control fields, it is possible to supply additional control fields to receive main or supplementary regulating intelligence. For instance, in certain speed control problems, it is desirable to limit the armature current which flows in the main machines to a definite value. An additional Rototrol control field is added and its circuit designed so that it takes control should the current exceed a definite value for either motoring or regenerative conditions. This field acts to hold the current within definite limits during acceleration or retardation and is particularly advantageous where the inertia of the mechanical

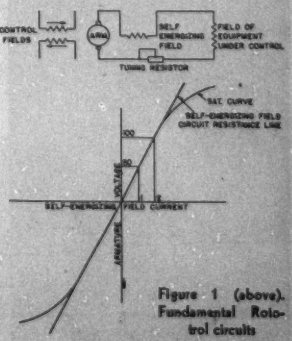

Figure 1 (above). Fundamental Rototrol circuits

Paper 46-57, recommended by the AIEE committee on industrial power applications and presented at the AIEE winter convention, New York, N. Y., January 21-25, 1946. Manuscript submitted November 23, 1945; made available for printing December 6, 1945.

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when arc voltages and circuit conditions are known.

References

1. A STUDY OF TRANSMISSION LINE POWER ARCS, Paul Ackerman. *Engineering Journal*, volume 11, May 1941, pages 309-23; 504

2. FREE BURNING HIGH CURRENT ARCS AT 100 KILOVOLTS A-C VOLTAGE, E. Gross. *Schweizer Archiv* (Solothurn, Switzerland), volume 7, July 1941, pages 196-201.

3. ELEKTRISCHER SCHALTVORGANGE (book), Reinhold Rüdenberg. Pages 304-15.

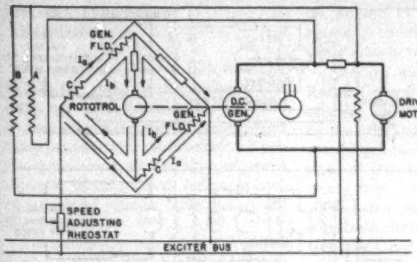


Figure 2. Elementary circuits of counterelectromotive force type speed regulator

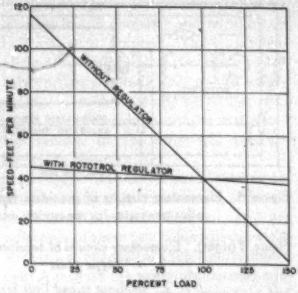


Figure 4 (right). Plot of test results at 1/30 speed for 150 horsepower supercalender drive with and without Rototrol counter electromotive force type regulator

system is large and a considerable period of time is required to accelerate from one speed to another.

The Rototrol is particularly well suited for application in closed cycle control systems. The criterion for a closed cycle system is that the deviation from the ideal performance be used to modify the flow of power to reduce the deviation. In such systems stability of operation must be carefully considered. A complete analysis of stability is beyond the scope of this paper, but a review of the factors that affect it is in order. The most important factors are the level of ampere turns in the control fields, the speed of response of the Rototrol system as determined by the time constants and mutual linkages of the various fields, series or parallel connection of the self-energizing field, and the electrical and mechanical inertias of the machines or system of machines under control. By proper evaluation of these various factors and care in the design of the system it has been possible to apply most Rototrols without the use of external stabilizing means. This makes the device well suited for industrial applications where simplicity of circuits and functions are desirable, both from the standpoint of operation and maintenance and of initial cost.

A few of the Rototrol circuits most commonly used with typical applications and operating results are described in the following paragraphs. These applications are chosen as indicative of the wide variety of functions which the device will perform.

Counterelectromotive Force Type Speed Regulator

The Rototrol counterelectromotive force type of speed regulator circuit is perhaps the most widely applied. Representative applications are feed drives for machine tools, adjustable voltage planer drives, high speed adjustable voltage elevator drives, skip hoist drives, and supercalender drives. It is applied where wide speed ranges are required with good speed regulation at all speeds, particularly at the minimum speeds. The circuit does not require a pilot generator to measure the motor speed, which results in a space saving about the machine and in a simplification of the electric equipment and circuits.

Figure 3. High speed supercalender equipped with Rototrol counterelectromotive force speed regulator

Figure 2 shows the elementary circuits of the Rototrol counterelectromotive force type of speed regulator. The speed of a d-c motor is given by the well-known formula,

$$S = \frac{V - (IaRa)}{K\phi}$$

in which S is the motor speed, Va, Ia, and Ra are armature circuit voltage, current, and resistance respectively, ϕ is the flux, and K is a constant depending on the motor design. If the motor is excited separately at constant potential, the flux may be assumed constant with small error. The motor speed is then proportional to the counterelectromotive force, which is the voltage across its armature minus the resistance drop in its armature circuit. Rototrol pilot field B measures the voltage across the armature, and pilot field A measures the armature current which is directly proportional to resistance drop. Field A is connected in opposition to field B, so that the net result of these two fields measures the motor counterelectromotive force, which is directly proportional to motor speed.

Rototrol fields C are connected in a bridge circuit with the generator field and perform the double duty of both pattern and self-energizing functions. All legs of the bridge are of the same resistance. The component of current Ia flowing from the exciter bus serves as pattern

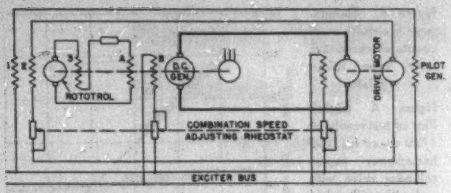


Figure 5. Elementary circuits of precision type speed regulator with pilot generator for measuring motor speed

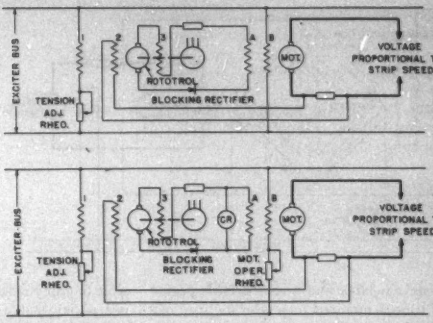


Figure 7 (right). Elementary circuits of tension control system for core type reels

a. Without speed limit feature
b. With speed limit feature

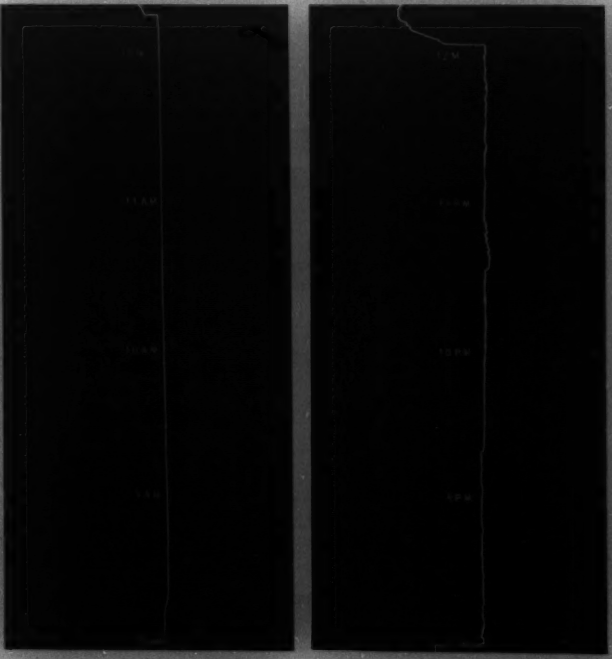
field current and in such a bridge will not cause a voltage drop across the Rototrol armature circuit. The component of current *Ib* flowing from the Rototrol armature through the bridge serves as the self-energizing component and conversely does not cause a drop across the terminals connected to the exciter bus. The circuits are arranged so that the pattern component of current through fields *C* is in opposition to the net effect of pilot fields *A* and *B*. Thus the pilot fields measure the motor speed and compare it with the pattern field component of current through fields *C*. If a difference exists, the Rototrol will compensate the generator field excitation and thus the motor speed until these fields again balance out.

A typical application of this circuit is to high speed adjustable voltage supercalender drives used in the paper industry. On supercalenders production speeds of from 1,200 to 2,000 feet per minute are becoming common, and the calender must be threaded at approximately 50 feet per minute, which results in an extremely wide speed range. Furthermore, the threading speed must be held constant for ease in threading and for safety to the operator. This requirement is complicated, because at threading speed the generator is operated near residual voltage, and a small change in residual voltage or in operating load means a relatively large speed change. Also as a result of threading the paper through the stack and the application of weighting, the load may vary 2 to 1 or more, which results in considerable speed variation with an unregulated drive.

In the past several methods of obtaining stable threading speed have been used. One method was to obtain part of the speed range by motor shunt field control which only partially eliminated the difficulty and was expensive because of the large frame size of the driving motor. Another method made use of a separate motor geared to drive the calender at threading speed to an overrunning clutch. This method gave stable threading speed but resulted in a complicated mechanical layout. The use of a Rototrol speed regulator obviates these disadvantages and is simple, as it requires only a small Rototrol set and a minor modification of the control circuits.

Figure 3 shows a view of a high speed supercalender driven by an adjustable voltage drive designed for a maximum speed of 1,200 feet per minute and a threading speed of 40 feet per minute. The entire range of 30 to 1 is obtained by armature voltage control. Figure 4 is a plot of test results at threading speed with and without the Rototrol regulator. Excellent regulation of threading speed is obtained as well as ample torque to break away the high static friction torques on the sleeve bearing stack.

Figure 6. Graphic speed charts taken on a 250-horsepower drive illustrating performance with (left) and without (right) Rototrol precision type regulator



Precision Type Speed Regulator

On applications where it is desirable to hold the speed of the driving motor within very close limits, a pilot generator for measuring motor speed directly is used in conjunction with the Rototrol. Typical applications of this type of speed regulator include drives for paper machines, wind tunnel propellers, and dynamometers.

The schematic diagram of a Rototrol regulator for precise speed regulation is shown in Figure 5. A pilot generator is used to measure the drive motor speed and excites the Rototrol pattern field 2. Pattern field 1 is excited from the exciter bus as is the pilot generator field. These fields are connected in series to minimize the effect of changes in exciter bus voltage and changes due to unequal field heating. The Rototrol excites generator field *A* and supplies only the regulating field power. Generator field *B* supplies the base excitation of the generator for any speed setting. To assure high sensitivity at all speeds, the speed adjusting rheostat is located in Rototrol field 2 which is served from the pilot generator so that a constant level of forcing excitation is obtained over the complete speed range.

When the drive motor speed is at the correct value, the control fields 1 and 2 balance out. If the motor speed departs from its correct value, the speed change is detected by the pilot generator and transmitted to the Rototrol pilot field 2. A difference then will exist between the pilot and the pattern fields, which causes the Rototrol to compensate the generator excitation to bring the motor speed back to the correct value.

Operating results with this type of Rototrol speed regulator have been excellent. Typical performance is shown by the graphic charts of Figure 6 showing speed regulation before and after application of the Rototrol regulator. The charts were taken on a 250-horsepower single-motor paper machine drive which was modernized by addition of the Rototrol speed regulator. The performance was obtained without the use and complication of supplementary amplifiers and demonstrates the high amplification and speed of response of the Rototrol.

Tension Regulator for Core Type Reels

In the steel, textile, paper, and rubber industries there are a large number of windup and unwind operations utilizing core type reels. A drive for such a reel must maintain constant tension in the strip and must change its speed continually and smoothly as the roll builds up from a small core to a full roll. A number of Rototrol controlled drives for this service have been applied. The Rototrol is used in conjunction with an adjustable-speed d-c motor which has a speed range by shunt field control equivalent to the ratio of the full roll diameter to the empty core diameter.

Figures 7a and 7b show schematically the circuits for a constant tension reel drive. The reel motor is supplied with a voltage proportional to strip speed, either from the adjustable voltage generator serving the main drive or from an auxiliary generator driven at machine speed. The Rototrol modifies the shunt field excitation of the motor to compensate for changes in roll diameter and to maintain uniform strip tension. This is accomplished by maintaining the motor armature current constant, and, as the supply voltage is uniform at any particular strip speed, the power output of the motor and the tension in the strip will be substantially constant.

In Figure 7a Rototrol pilot field 2 measures the motor armature current and compares it with pattern field 1. Any net difference of these two fields will cause the Rototrol to change the excitation of motor field A to hold the armature current constant. Field *B* is the speed limit field and is adjusted to give a motor speed proportional to empty core diameter. The blocking rectifier situated in motor field *A* prevents reversal of this field in the event of a break or end of the material being reeled. Under these conditions the power formerly taken by sheet tension acts to accelerate the motor toward higher speed, and the Rototrol gradually will weaken field *A* until it is at zero excitation, at which time the blocking rectifier prevents reversal. With this scheme the equipment will accelerate to empty core speed when a break or end occurs. This is desirable when a new roll is to be started but is undesirable when rethreading is necessary.

Figure 7b shows the equipment modified to obtain a speed limit feature on strip breaks. Motor field *B* is the main field and is adjusted by a motor-operated rheostat. Field *A* receives its excitation from the Rototrol. As the roll builds up, field *A* is strengthened gradually, and the voltage across relay *CR* increases until the relay picks up. The relay contacts energize the motor-operated rheostat in such a direction as to strengthen field *B*. Simultaneously the Rototrol will decrease the excitation of field *A* in accordance with the regulator requirement of constant current in the motor armature circuit. This action progresses until relay *CR* drops out and stops the motor-oper-

Figure 8. Core driven beam of a slasher in the textile industry using Rototrol control for speed and tension

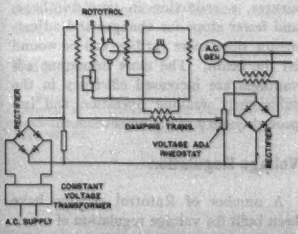


Figure 9. Schematic diagram of Rototrol voltage regulator applied to an a-c generator

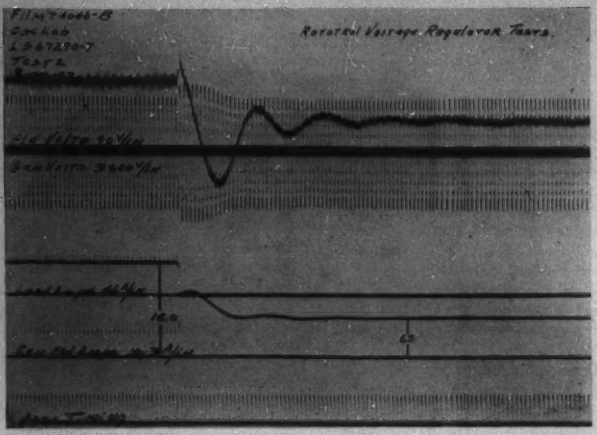


Figure 10. Oscillograph showing performance of Rototrol voltage regulator on release of 70 per cent power factor load on a-c generator

ated rheostat, and the cycle is restarted. A paper break under this condition will only speed the equipment up until field *A* is at zero excitation, as it cannot reverse because of the blocking rectifier. By proper relay selection this speed-up can be limited to between 10 and 20 per cent. Thus the roll is essentially at the proper speed, and rethreading is easily accomplished.

The strip tension is adjustable by means of a small manually operated rheostat located on the operator's panel. These adjustments may be observed readily on the motor ammeter which serves as a relative indication of tension and permits duplication of results to obtain the most satisfactory roll for any given weight and grade of material.

Essentially the same type of circuits are applied to unwind stands wherein the operation is reversed and the regenerative power fed back into the system.

Figure 8 illustrates the application of Rototrol tension control to the core driven beam of a slasher in the textile industry. Constant tension on the thread comprising the beam results in uniform beam diameter, a reduction in yarn breakage, and fewer stops for changes and adjustments, since more yardage can be wound on the beam. The more important advantages are increased efficiency in the subsequent weaving operation and improved quality of the finished cloth.

Voltage Regulation

A number of Rototrol exciters have been built for voltage regulation of a-c or d-c generators. Figure 9 illustrates the essential circuits of the regulator as applied to an a-c generator. The generator voltage is measured through a transformer and dry type rectifier and bucked against the rectified voltage of the constant voltage transformer. The difference controls the Rototrol excitation through field 1 to restore normal generator voltage. To obtain a high degree of stability, a damping transformer is used in the control field circuit. Where use of an a-c supply for the constant voltage transformer is not advisable, static "intersecting impedance" networks have been applied.[1]

To obtain high rates of response both parallel and series self-energizing fields are used. The circuit is tuned by adjustment of the resistor in field 2, so that fields 2 and 3 sustain the Rototrol output at any point on the straight portion of the saturation curve. This arrangement takes advantage of the almost instantaneous transient change in generator field current and provides extremely fast response of the Rototrol exciter.

Typical performance is shown by the oscillograph of Figure 10 which was taken during the sudden release of full load at 70 per cent power factor on a 150-kva 3-phase 60-cycle 2,400-volt generator controlled by a Rototrol voltage regulator. The voltage was returned to normal in 1/4 of a second with very little overswing. The oscillograph demonstrates excellent stability as well as very high speed of response of the Rototrol exciter.

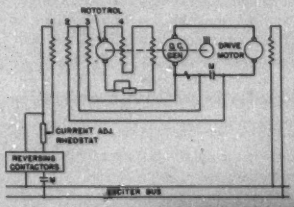


Figure 11 (above). Elementary diagram of Rototrol current regulator applied to a large tire testing machine

Figure 12. Tire testing machine using Rototrol acceleration control

Acceleration of High Inertia Loads

The Rototrol has been applied to many problems concerning acceleration and retardation of high inertia loads. For such problems it is desirable to accelerate at uniform torque from minimum to maximum speed, to reduce the current peaks and mechanical shock experienced with step type controllers, and to eliminate many of the relays and contactors associated with conventional magnetic control. The Rototrol is able to perform these various requirements with a surprising simplicity of the control circuits. Typical applications are bomb spinners, centrifugal casting machines, balancing machines, tire testing machines, and large mine hoists.

Figure 11 shows schematically the circuits of a Rototrol exciter as applied to a large tire testing machine drive. The machine consists of a flywheel which is accelerated to various speeds and then stopped by bringing the tire into contact with it. The huge flywheel has a WR^2 of 10,000,000 pound feet squared and requires an accelerating torque equivalent to 400 horsepower at 350 rpm to reach maximum speed in 30 minutes. The Rototrol is arranged to control the armature current and thus the torque of the separately excited drive motor. As the system gradually speeds up, the Rototrol increases the generator voltage to maintain uniform accelerating torque. The control is arranged to provide regenerative braking to standstill by simply reversing the pattern field 1 when such operation is necessary.

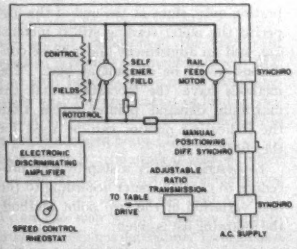


Figure 13. Simplified diagram of feed drive for large boring mill using a Rototrol in combination with an electronic discriminating amplifier

After the system is up to speed and the motor and generator disconnected, the generator voltage is matched automatically to the motor counterelectromotive force. This is desirable so that the circuits may be reclosed at any time for retardation or further acceleration. This function is accomplished by connecting Rototrol field 3 across the main circuit contactor *M* and de-energizing pattern field 1 when *M* is open. Any voltage difference will cause current to flow in field 3, which modifies the Rototrol and generator voltages to reduce the difference.

Helper Drive Torque Control

The circuit of Figure 11 with omission of field 3 has been used rather widely as a driving effort or torque regulator for helper drives operated in conjunction with a main drive. The system is applicable to either mechanically or electrically driven machines. Typical applications are the various auxiliary drives for the wet ends of paper machines and top roll drives for press rolls which are used in many industries. This arrangement assures constant helper motor torque over a wide speed range, regardless of speed variation of the main drive or changes in effective roll diameter due to change in nip pressure on soft rolls. Often a number of motors are served by a common generator. Here the total driving effort of the motors is determined by the Rototrol with the division of load secured by individual motor shunt field rheostats.

Speed Matching

Electronics often is used in combination with the Rototrol to solve difficult drive problems. An interesting application is the feed drive for a large vertical boring mill. The Rototrol is used with an electronic discriminating amplifier, and the circuits are arranged to provide either speed matching of the feed motion to the main table drive or straight speed control of the feed.

The elementary circuits are shown in Figure 14. For matching the speed of the feed screw motor to the speed of the table, small synchro units are driven from the feed screw motor and from the table drive. Angular displacement between the synchros will cause an error voltage which is fed into the electronic discriminating amplifier. The amplifier senses the direction of the error and changes the current through the Rototrol control fields to modify feed screw motor speed to reduce this angular difference. The system accurately matches the relative speeds of the feed and table over the complete range of table speed. Adjustment of relative speeds is obtained by the adjustable ratio transmission between the table and the synchro unit.

It is also desirable to operate the feed motor on straight speed control capable of adjustment over a wide range and with good speed regulation at all speeds. The discriminating amplifier is designed for this function and provided with a transfer switch to effect changeover. The motor counterelectromotive force is measured by means of armature current and voltage and balanced against a standard voltage in the discriminating amplifier. The difference controls the Rototrol excitation to maintain the proper motor speed.

This type of drive simplifies the mechanical parts of the machine by eliminating the many gear changes and the mechanical connection from the table to the feed screw on the rail. The large number of feed speeds, readily available, facilitates machine adjustment and results in increased production.

Conclusion

The large number of Rototrol applications have proved it to be an excellent and versatile regulator for industrial service. Operating experience has shown that it can be understood by nontechnical maintenance personnel, that its inherent reliability and stability assure trouble free operation with relatively little maintenance, and that it combines the necessary degrees of amplification and speed of response to meet the requirements of industrial problems. Existing applications cover a wide field, and the future holds considerable promise of broader utilization.

Reference

1. Static Voltage Regulator for Rototrol Exciter, E. L. Harder, C. E. Valentine. AIEE Transactions, volume 64, 1945, August section, pages 601–06.

Thermal-Demand-Meter Testing Techniques

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THIS PAPER is written to encourage thinking and development on the subject of thermal-demand-meter testing procedures with specific reference to the development of shorter testing techniques. Conventional test methods in the past have involved relatively long periods of load holding to bring the meters under test to thermal equilibrium for the calibration check and adjustment. With the increasing use of thermal meters it is desirable to use some testing method which more nearly resembles tests on watt-hour meters. This paper outlines three general methods for shortening the test time and leaves to the reader the choice of the method, or modification of it, best suited to his requirements.

The principal problem in thermal-demand-meter testing is to determine the ultimate or final indication of the meter on constant load at thermal equilibrium. The response characteristic of the particular meter being tested will influence the available techniques for obtaining this information in short periods of time. This discussion is limited to meters having a simple logarithmic response, such as the meter shown in Figure 1, the characteristics of which have been covered in a previous article.[1] Appendix A gives an arbitrary definition and a mathematical description of this characteristic, and Appendix B demonstrates its importance in facilitating the establishment of a simple and sound short test method.

At the present time it is customary to return thermal demand meters to the laboratory for checking and calibration. The following or a similar step-by-step procedure usually is followed:

1. Connect meters in gangs, and apply potential to each for 2 to 24 hours.
2. Check the zero reading, and adjust if necessary.
3. Apply load to be checked, and hold constant for 45 minutes.
4. Check the meter indication against the load held, and adjust if necessary.

Paper 46-69, recommended by the AIEE committee on instruments and measurements and presented at the AIEE winter convention, New York, N. Y., January 21-25, 1946. Manuscript submitted November 23, 1945; made available for printing December 14, 1945.

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A short test method for checking thermal meters should be a distinct advantage to electric power companies, particularly as a means of checking the accuracy of these meters on the customers' premises in relatively short periods of time.

For a meter possessing the simple logarithmic response characteristic, mentioned previously, three general types of short test methods have been suggested and evaluated. Though other methods and modifications may be developed, particularly for meters having other than a simple logarithmic response, the three general types described herein provide an opportunity for large reductions in the testing time or man-hours for meters having this characteristic. The following terms have been coined to identify these three methods:

(*a*). "Two point method."
(*b*). "Double load method."
(*c*). "Thermal standard method."

The two point method is adaptable to testing on customers' premises. A graph or tabulation can be used to simplify the procedure. The double load method in one form is best adapted to testing single meters, whereas another form is more suitable for gang testing in the laboratory. The thermal standard method is usable on either gang or individual testing and is useful in its man-hour saving, although the elapsed time of test may not be shortened materially.

The Two Point Method

As the name denotes, the two point method involves obtaining sufficient readings of the meter indication at known intervals of time to predict the ultimate indication. The method is based on the solution of simultaneous equations, derived from equation 2 in Appendix A.

$$D = W(1 - e^{-kt})$$

where

D = instantaneous deflection
W = ultimate deflection
t = time
k = a constant
e = 2.72

An examination of this equation shows that there are two unknown quantities, namely k and W, when the quantities D and t are determined by simultaneous readings of the meter indicating pointer and a stop watch. Since there are two unknowns in the equation, two sets of values D and t must be determined to give two equations from which W and k can be found. To substitute the readings into the equation and perform the solution would be needlessly laborious for the meter tester, as the solution can be set up in the form of a graph. Two variations of the test are possible. In one, the pointer readings at two given times after constant test load application are used to indicate the ultimate reading. In the other, the time intervals that are required after constant load application for the meter to indicate two different scale points are used to compute the ultimate meter reading. Each of the two point methods is adapted to checking only one meter at a time, and is suitable for checking the calibration only, since at the end of the test period the meter reading still is increasing, and an adjustment under these conditions would be difficult at best. The methods have the advantage that the maximum demand pointer rather than the indicating pointer can be used for the check.

To describe briefly a step-by-step procedure to check a meter according to the first variation of the two point method, the following list is given:

1. Reverse potential with a load applied until indicating pointer reads zero.
2. Start stop watch and simultaneously apply a known load and hold constant.
3. At 3 minutes (or any other suitable time depending on the charts set up) after the load is applied, read the meter indication. Continue holding load.

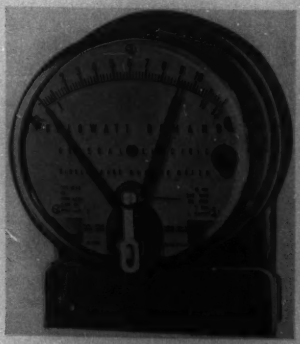


Figure 1. Thermal watt demand meter having a simple logarithmic response characteristic

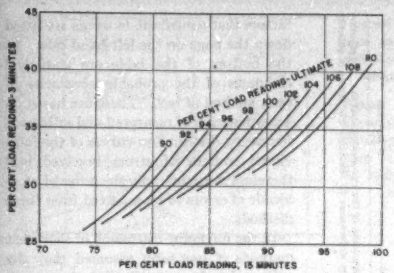


Figure 2. Chart to determine ultimate deflection when indication is read after a given time

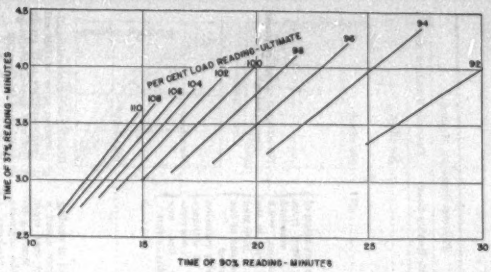


Figure 3. Chart to determine ultimate deflection when time is read for a given indication

4. At 15 minutes (or any other suitable time depending on the charts set up) after load is applied, read the meter indication.

5. Check the charts (Figure 2) to find the ultimate indication of the meter—compare this with what the ultimate indication should be from the load held.

The step-by-step procedure for using the second variation of the two point method is similar to the first, except that two stop watches are started simultaneously with the application of load in step 2, and one is stopped as the pointer reaches a predetermined point (37 per cent of the load applied); the other is stopped when the pointer reaches another predetermined point (90 per cent of the load applied). From the stop watch readings the ultimate deflection is determined from a chart (see Figure 3).

The Double Load Method

The double load method, as the name indicates, requires the application of double load to the meter under test for an interval of time, followed by a short period of holding the test load. Two variations in the general method are apparent: first, the double load may be held for a specified length of time; or second, the double load may be held until a definite indication on the meter is attained. An outline of step-by-step procedure for the first follows:

1. Reverse potential until meter reads zero indication. (Gang test meters will read zero at end of potential preheat.)
2. Apply double load for a specified time.
3. Cut load to test load, and hold constant for a specified time.
4. Read meter and compare it with the load value being held.
5. Make any adjustment necessary in the meter.

This procedure is adapted to gang testing of meters if desired, and the meter may be adjusted at the end of the test. The indicating pointer must be used during the test rather than the maximum demand pointer, as the indication at the end of the test may be lower than at the end of the double load period.

A step-by-step procedure for the second double load variation follows the first, except that the meter need not necessarily read zero at the start of the double load period, and the load should be reduced to the test load as soon as the meter reads the test load. Obviously this procedure is suitable for testing only one meter at a time. It does allow adjustment of the meter at the completion of the check.

The Thermal Standard Method

The thermal standard method requires the use of an accurately calibrated thermal meter of approximately the same response characteristics as the meter under test. Two variations of this method suggest themselves. The first is actually a combination of the double load and test standard methods. The second, which does not involve applying double load, conserves man-hours but does not reduce testing time appreciably.

Both variations of the thermal standard method are suitable for either single-meter or gang testing. Adjustments can be made on the meters at the conclusion of the test, since the test meters are at thermal equilibrium. The indicating pointer must be used rather than the maximum demand pointer, since load variation may cause a downward pointer movement during the test. The use of the accurately calibrated thermal meter as a standard eliminates the necessity for precise load holding, although reasonable limits must be maintained, so that differences in the response time of the test meter and the standard do not introduce errors.

The sequence of operations for the procedure using double load is as follows:

1. Reverse potential on test meter, and bring reading to zero.
2. Connect standard and test meter to same load.
3. Apply double load to both meters until the standard one indicates the value of the test load.
4. Drop to the test load and hold approximately correct load for a specified time.
5. Compare the reading of the standard meter under test.

The second procedure is simply to connect the accurate, standard meter and the meter under test to the same load and leave them for three or more demand intervals,[3] for example, 45 minutes for a meter used on 15-minute demand interval service. At the end of that time the deviation of the reading of the meter under test from the standard meter indicates the error of the meter under test.

In the descriptions of the various methods given, only a single point check of the meter has been considered. If the zero position of the indicating pointer is not correctly set on the scale zero, errors at points other than the one checked will be present. With a meter that does not overshoot on transient load, the following step-by-step procedure is suggested for checking the zero when desired:

1. Reverse potential, and apply load until indicating pointer reads zero.
2. Remove load, and reconnect potential.
3. With potential applied wait for one demand interval, and note the indication of the pointer. If no appreciable change has taken place, the meter is very close to correct zero. Any change that has taken place represents 90 per cent of the total deviation from zero at thermal equilibrium, and an adjustment can be made on this basis.

In connection with this brief description of some possible methods of shortening the test time a comparison of the accuracy of the various methods is given in Table I. The three test methods are listed across the top of the table, and the

Table I. Estimated Errors When Using Short Test Methods

Factors Influencing Errors	Two Point Method		Double Load Method		Thermal Standard Method	
	Indication at Given Time	Time for Given Indication	Held for a Definite Time	Held to a Definite Indication	Combined With Double Load	Thermal Standard Alone
1. Zero adjustment	No effect	No effect	No effect	No effect. ±.5 per cent calibration error causes about ±0.5 per cent error in the ultimate indicated reading at end of one meter period	No effect	No effect
2. Initial calibration	No effect	No effect	No effect		No effect	No effect
3. Time of response deviation	No effect	No effect	±1 minute deviation of response time from value for which test is devised gives about ±0.5 per cent ultimate indication error at end of one meter period	Insignificant effect	±1 minute deviation of response time from thermal standard causes about ±0.5 per cent error in the ultimate indicated reading at end of one meter period	No effect if meter response times match*
4. Test timing	±seconds on 3-minute point gives about ±2 per cent; ±5 seconds on 15-minute point gives about ±⅓ per cent (depends on calibration of meter)†	±5 seconds on 37 per cent point gives about ±1 per cent; ±15 seconds on 90 per cent point gives about ±⅓ per cent (depends on calibration of meter)†	±30 seconds in time at which double load is removed to single value causes about ±0.2 per cent error	No reasonable variation in time of ultimate reading (±several minutes) will have any appreciable effect	No reasonable variation in time of ultimate reading (±several minutes) has any appreciable effect	No effect
5. Load holding accuracy	±1 per cent load error gives ±1 per cent error	±1 per cent load error gives ±1 per cent error	±1 per cent error in double load causes ±0.1 per cent error; ±1 per cent error in test load causes ±1 per cent error	Error in double load has no effect; ±1 per cent error in test load causes ±1 per cent error	No effect*	No effect*
6. Reading accuracy	±1 per cent on zero reading gives ±1 per cent error; ±1 per cent on 3-minute reading gives about ±2 per cent error; ±1 per cent in 15-minute reading gives about ±2 per cent error	±1 per cent on the zero reading gives about ±1 per cent error; ±1 per cent on 37 per cent point gives about ±1 per cent error; ±1 per cent on the 90 per cent point gives about ±⅓ per cent error	±1 per cent in reading zero causes ±0.1 per cent error; ±1 per cent in reading 37 per cent causes ±1 per cent error	Error in reading zero does not produce any error; ±1 per cent in reading 37 per cent causes ±1 per cent error	±1 per cent in reading zero causes about ±0.1 per cent error or less. Reading error at the ultimate reading produces a corresponding error	Reading accuracies and calibration are only errors of any appreciable magnitude in this method
7. Over-all accuracy (estimated)	±3 per cent	±2.5 per cent	±2 per cent	±2 per cent	±2 per cent	±2 per cent

* In the thermal standard methods load variation during the test will not produce any error in the ultimate deviation of test meter from thermal standard, provided that the response time of the two meters match. If response times are different on the test meter and the standard, load variations will cause indication differences. For reasonable load variations (±5 per cent) and reasonable response time differences (3 minutes) the errors in general from this source should be within ±⅓ per cent to ±1 per cent. † See Figure 3.

factors that contribute to errors are listed down the page on the left-hand side. At the bottom of the table are statistical estimates of the probable accuracies of each method of test. These are based on a combination of measured and estimated frequency distribution curves of the individual sources of errors involved and therefore represent only the order of magnitude of errors to be expected from these methods.

In the foregoing discussion of short test methods it has been assumed that the voltage has been applied to the meters for a sufficient length of time to produce complete change in the zero indication of the meter due to potential alone. In the case of periodic accuracy checks on customers' premises this undoubtedly would be the fact. In the case of gang testing in the shop time must be allowed for this item. In the methods where ultimate indication practically is reached, such as the double load or thermal standard methods, this potential preheating time may be overlapped with the time required to obtain final indication.

Conclusion

The purpose of this paper is to stimulate thought and experiment on short test methods and to indicate that such methods are possible. The procedures outlined are intended to show only the general steps in the various methods and are not to be considered detailed instructions for testing meters. Quite probably methods other than those suggested can be devised, and modifications and combinations of the methods discussed may be developed. Although it is possible that test methods can be found that will shorten materially the testing time of indirectly heated meters, nevertheless, this discussion has been limited entirely to testing meters with a simple logarithmic response characteristic that will not overshoot on transient load. This characteristic is realized on some thermal meters using direct (or internally) heated bimetallic spirals. Although actual test data are limited, nevertheless it indicates that short test methods are practicable when the greatest accuracy is not required.

Appendix A. The Meaning of a Simple Logarithmic Average

The simple logarithmic average is mentioned a number of times in the main portion of the paper. In this appendix an arbitrary definition of it will be given, and it will be expressed in mathematical symbols.

An understanding of the simple logarith-

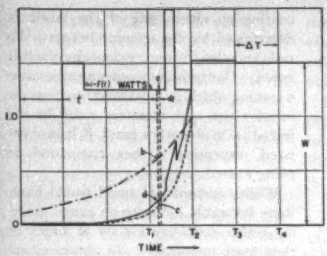
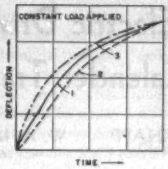
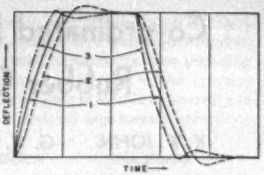


Figure 4 (left). Curve used to illustrate a definition of logarithmic average



A



B

Figure 5 (right). Curves showing overshooting and dipping characteristics of typical thermal meters

mic average is obtained best by comparing it with the arithmetic average. In demand metering both averages are used, and each has been found satisfactory for assisting in obtaining information necessary for billing. In considering an average of watts such as curve a in Figure 4, the arithmetic average at time T_2 can be expressed by $1/(T_2-T_1)\times\left(\int_{T_1}^{T_2} w\,dt\right)$ where $w=f(t)$ and represents the watts and where T_1 and T_2 are the beginning and end of the time interval concerned. If the time interval is extremely short, T_2 nearly equals T_1, and the arithmetic average approximates the instantaneous value. If the time interval is extremely long, all past watt values are given equal importance. Because in many cases neither of these arithmetic averages gives exactly what is wanted for demand purposes, the average over a given period of time, such as 15 minutes, often is used. Most mechanical demand meters indicating this sort of average do not do so continuously but do their integrating continually over definite intervals, so that changed readings are available only at the end of definite time intervals. Thermal meters indicating a logarithmic average are expected to do so continuously.

The simple logarithmic average of the watts curve will be considered as the area under a weighted curve (d in Figure 4), which is made up of the product of all points a (on the watts curve) multiplied by corresponding points on a weighting curve c. The weighting curve follows the simple logarithmic form $e^{-k(T_2-t)}$ where T_2 is the time at which the average is expressed and t is the time at which the watts were a. Mathematically it is expressed:

The simple logarithmic average,

$$D=K_1\int_{-\infty}^{T_2}[f(t)]\,[e^{-k(T_2-t)}]dt$$

The proportionality factor K_1 is chosen such that for any constant load W the logarithmic average is numerically equal to the load W. It is therefore equal to the arithmetic average which is also W. That is,

$$D_{(\text{For constant load})}=K_1\int_{-\infty}^{T_2}We^{-k(T_2-t)}\times dt=W$$

This equation is satisfied only if $K_1=k$. Therefore

$$D=k\int_{-\infty}^{T_2}[f(t)]\,[e^{-k(T_2-t)}]dt \qquad (1)$$

For constant load applied from zero indication this reduces to:

$$D_s=W(1-e^{-kt}) \qquad (2)$$

The choice of weighting curve determines the response characteristic of the meter, and for simple logarithmic weighting curves the value of k in the expression $e^{-k(T_2-t)}$ controls the relative effect of recent and remote loads. Figure 4 shows two weighting curves, curve c has k equal to 0.1535 corresponding to a 15-minute meter interval, while curve b has k equal to 0.0384 corresponding to a 60-minute meter interval.

The simple logarithmic average then is simply a value proportional to the arithmetic average of the weighted curve that is obtained when the watts curve is multiplied by a simple logarithmic weighting curve.

It has been shown previously[1] that, although the theoretical weighting curve of thermal watt demand meters is of the nature of a simple exponential curve, nevertheless the characteristics of many commercial meters differ appreciably from this ideal. However, it also has been shown that an internally heated bimetal type of meter as built does have this form of response, and it will be shown in Appendix B that such a meter will neither overshoot nor undershoot, nor will it have an indication dipping characteristic.

Appendix B. Why Simple Logarithmic Average Thermal Demand Meters Will Not Overshoot

In this paper it is disclosed that meters with certain response characteristics are well adapted to short testing methods. Meters having these characteristics measure a simple logarithmic average and, since they respond in this manner, they will neither overshoot nor dip. The proof of this will follow, but first it is necessary to understand what is meant by overshoot and dip.

Overshoot and Dip

If the pointer of a thermal meter is moving upscale owing to a relatively high load, and the load is reduced suddenly to a value close to the indication of the meter, a temporary dipping of the pointer below the instantaneous load is called dipping. If it continues temporarily to increase above the instantaneous load, it is said to overshoot. Neither condition is especially desirable when testing meters by a short method, but each characteristic can and does occur in some commercial thermal meters.

Proof That Simple Logarithmic Meters Will Not Overshoot

In order to prove that some meters cannot overshoot, a time will be taken (T_3 in Figure 4) at which the indication is a given value W. It then will be shown that, if a constant load W is held from this time on for some definite time interval (ΔT), the indication of the meter will not be changed. Since ΔT is chosen arbitrarily, it may be as long or as short as desired and even may be an an infinitesimally short time dt. Since the indication of the meter does not change for any of these conditions, it will have been proved that there is no tendency to overshoot, undershoot, or dip. The meter involved is assumed to measure a simple logarithmic average demand.

At the time T_3 the indication has arrived at a value W by any means whatever in its past history.

$$\text{Indication at } T_3=k\int_{-\infty}^{T_3}[f(t)]\times[e^{-k(T_3-t)}]dt=W \qquad (3)$$

At some later time (T_4) the indication is by definition:

$$\text{Indication at } T_4=k\int_{-\infty}^{T_4}[f(t)]\times[e^{-k(T_4-t)}]dt \qquad (4)$$

This indication (at T_4) can be separated into the integrals $\int_{-\infty}^{T_3}+\int_{T_3}^{T_4}$ as follows, since the load is constant from T_3 to T_4.

$$\text{Indication at } T_4=k\int_{-\infty}^{T_3}[f(t)]\times[e^{-k(T_3+\Delta T-t)}]dt+k\int_{T_3}^{T_4}We^{-k(T_4-t)}dt \qquad (5)$$

Since $e^{-k\Delta T}$ is a constant for a particular value of (ΔT) and since e^{-kT_4} is a constant for a particular value of T_4, they can be taken outside the first and second integrals respectively.

$$\text{Indication at } T_4=[e^{-k\Delta T}]\times\left[k\int_{-\infty}^{T_3}f(t)e^{-k(T_3-t)}dt\right]+[kWe^{-kT_4}]\left[\int_{T_3}^{T_4}e^{kt}dt\right] \qquad (6)$$

From equation 3 and a solution of the

Co-ordinated Electric Drive for a Rubber Calender Train

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Synopsis: The continuous process of coating fabrics with rubber, such as is used in tire manufacturing, involves several individual machines that present operating problems not met successfully by mechanical drives. A new co-ordinated electric drive has been developed which does meet these requirements using amplidyne, and also electronic, control. It is expected that quality and production will be improved by this equipment. The means employed may be applied successfully to other industries.

IN THE MANUFACTURE of many rubber goods, textile fabrics are coated on both sides with rubber in a machine called a calender. Associated with the calender are auxiliary devices for handling the fabric before and after coating, making up a processing train.

Tire fabrics are one of the most important examples of this process in the rubber industry[1] and their production in a calender train, using a newly developed electric drive, will be discussed in this paper. The complete equipment now is installed in the Detroit, Mich., plant of the United States Rubber Company and parts of it are shown in Figures 1 and 2.

The calender itself, the train auxiliaries, and all of the electric equipment were manufactured from designs which were co-ordinated closely by the operating company, the machinery builders, and the electrical manufacturer. The importance of this procedure will be appreciated readily from the operating requirements.

Description of Process

A schematic diagram showing the mechanical arrangement of the processing train is shown in Figure 3.

Rolls of fabric are started at one of the entry letoffs. A maximum diameter of 42 inches can be accommodated. The fabric widths vary up to 60 inches.

The entry festoon forms a storage reserve of 80 feet of fabric so that the letoff can be stopped for changing rolls without shutting down the calender. The alternate letoff positions are provided to save time during this operation.

After drying, the fabric enters the calender rolls as shown. These rolls are 32 inches in diameter and 70 inches wide. Rubber from the top bank coats the upper side of the fabric, while that from the lower bank coats the under side.

The thickness or "gauge" of the rubber coating on either side of the fabric is determined by the opening between the rolls and also, to some extent, by the roll speed. Gauge is very important because a coating which is undersized produces an inferior tire and therefore must be rejected. On the other hand, if it is oversized, expensive rubber compound is being wasted.

While constant roll speed would have some favorable influence on gauge, there is another consideration for it which is even more important. To obtain maximum production, the calender rolls should run continuously at the maximum speed which certain processing limitations allow. This speed depends on the type of compound and fabric, and usually is established by considerations of plastic flow. If no means are provided for holding the calender speed at that maximum value, the average speed at the end of a day may be somewhat less. Even if this is only a small amount, a surprising amount of production can be lost.

The delivery festoon provides 64 feet of space for storing fabric when changing rolls at the windup. Finished rolls are wound on one of the fabric windups. The maximum diameter, as in the case of the letoff roll, is 42 inches. Alternate windup positions also are provided here. To keep layers of stock from sticking together, a separator or "liner" also is wound on the roll. This is supplied from a separate liner letoff for each fabric windup. Sometimes coated fabrics are run through the calender train a second time. For this purpose, liner windups also are provided at the entry letoffs.

Operating Requirements

The operating speed range of the train is from 7 to 70 yards per minute. A sepa-

Paper 46-56, recommended by the AIEE committee on industrial power applications for presentation at the AIEE winter convention, New York, N. Y., January 21–25, 1946. Manuscript submitted November 16, 1945; made available for printing December 5, 1945.

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second integral with respect to t:

Indication at T_4

$$= [e^{-k\Delta T}][W] + [kWe^{-kT_1}] \times \left[\frac{1}{k} e^{kt}\right]_{T_3}^{T_4}$$

$$= [e^{-k\Delta T}][W] + [We^{-kT_4}] \times [e^{kT_4} - e^{kT_3}]^{T_4}$$

$$= [e^{-k\Delta T}][W] + [W][1 - e^{-k(T_4 - T_3)}]$$

$$= We^{-k\Delta T} + W - We^{-k\Delta T}$$

(since $T_4 - T_3 = \Delta T$)

$$= W \qquad (7)$$

Thus the indication at T_4 is the same as that at T_3 (no matter what the time interval between T_3 and T_4), and therefore there has been no tendency to overshoot, undershoot, or dip.

Since the foregoing is based only on the indication of a meter whose response meets this definition of a simple logarithmic average, it is to be expected that some meters whose response differs from this average can overshoot or undershoot, or may have a tendency to dip. That this is true is shown in Figure 5, where A shows the response of three designs of commercial meters with different response characteristics when subjected to a constant load, starting from zero.

Figure 5B shows the response of these same meters when double load is applied until the pointers reach a given indication and then the load is changed to a constant load which ultimately will give this same indication. The loads are changed on the 3 meters at different times, since they arrive at the given indication at different times. All meters are correctly calibrated. The potential is reversed, and the meters run to zero. As each meter reaches zero its potential is returned to normal and its current reduced to zero. It can be seen that both meters 2 and 3 overshoot or undershoot considerably or have the characteristic of indication dipping.

When, therefore, it is desirable to eliminate overshooting or undershooting indication in order to save time during short tests or for any other reason, a meter whose response follows the simple logarithmic average should be chosen. It will neither overshoot nor undershoot, nor will it have the indication dipping characteristic.

References

1. THEORETICAL POSSIBILITIES IN AN INTERNALLY HEATED BIMETAL TYPE OF THERMAL WATT-DEMAND METER, E. E. Lynch. AIEE TRANSACTIONS, volume 61, 1942, October section, pages 764–70.

2. CODE FOR ELECTRICITY METERS. Edison Electric Institute.

rate threading speed of 7 yards per minute also is provided for running-in the fabric initially.

The calender itself should be able to operate over the speed range, independent of its train auxiliaries, for "warming up" operations when first starting. It also should be capable of reversing, with and without the central auxiliaries.

Jogging operation, forward or reverse, is required for all of the windups and let-offs. This is used either when starting or finishing up a roll that is not in train operation.

Emergency stopping is provided for the complete train from a number of control positions located throughout its length. This is an important requirement for the safety of operating personnel. There is a national code which specifies certain stopping performance that must be met.

In addition to the foregoing operating requirements, it is very desirable to maintain the tensions in the fabric, on either side of the calender, at constant values. These tensions are such that those before the calender exert a drag on it, while those after the calender are in the pull direction. The calender rolls, then, driven at constant speed, provide the necessary reactions for these tensions as a reference point. The benefits of constant tension to each part of the train have been tabulated at the bottom of Figure 3.

Past Practice, Mechanical Drive

In the past, calender trains have been driven by a single motor connected to the calender through a gear reducer. At some spot on the calender a mechanical takeoff was provided to drive a line shaft through gearing. The line shaft usually extended the length of the train and the auxiliaries were driven from it through right-angle gears, chain drives, and so forth.

Naturally, the electric drive with proper control equipment could be made to fulfill the operating requirements for the calender itself, but mechanically driven auxiliaries fall short of the mark.

To adjust tension, friction clutches and adjustable speed transmissions have been employed. These devices are not self-regulating and the operators must readjust them frequently. This is not practicable and, as a result, optimum adjustments seldom are obtained and production may suffer.

Furthermore, if good adjustments of tension have been made, there is no means for holding them there, nor can they be measured for future reproduction on other runs. There is another disadvantage in that maintenance is quite high on the friction clutches and the other mechanical component parts.

Electric Sectionalized Drive

With the electric drive, the entire train is sectionalized so that each auxiliary which ordinarily would have a mechanical drive is provided with its own motor. Co-ordinated control takes the place of the line shaft tie and, in addition, provides the proper tensions and speeds. Furthermore, once optimum adjustments have been established, the control holds them there. Electric instruments make it possible to take measurements and record the adjustments. Thus, if that same run is to be repeated in the future, the best operating conditions can be obtained very quickly.

The various pushbuttons and rheostat dials which are used for the adjustments are located remotely from the driven auxiliaries, in convenient groups. Each group consists of several interdependent and related adjustments, thus providing maximum convenience to the operator and also a more favorable opportunity to make correlated adjustments correctly.

Circuits

Power Circuits

The general arrangement of the power circuits for the various drives is shown in Figure 3.

The main drive for the calender is of the adjustable voltage (Ward-Leonard) type, providing ten to one speed range, of which five to one is by armature voltage control and two to one by motor field control.

The adjustable voltage scheme was selected because of the wide operating speed range and the advantage of being able to control the speed of the motor by adjusting its armature voltage. Furthermore, as has been pointed out by Cassidy and Mosteller,[1] the first cost is less.

The motor field range is used because at low operating speeds (below basic speed), substantially more than constant torque may be required by the calender.

The group of drives which is called the "central auxiliaries" always operates at the speed of the calender. They are not supplied, however, from the calender generator. This is done primarily for reasons of simplicity. For example, the auxiliary motors themselves are much smaller than the calender motor so that their IR drops are considerably higher. Thus, at one-tenth speed the terminal voltage that they require would be sub-

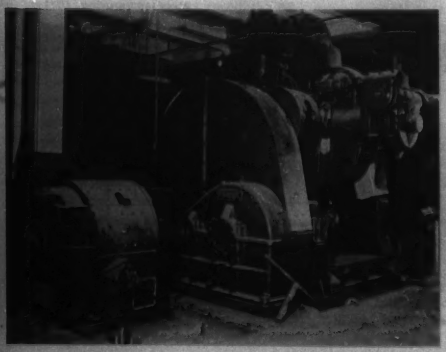

Figure 1. Calender and driving motor

Figure 2. Calender motor-generator set and d-c control panels

One of the auxiliary motor-generator sets is in the background

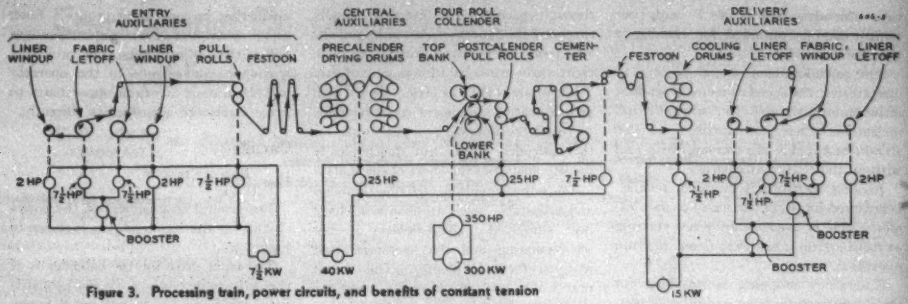

Figure 3. Processing train, power circuits, and benefits of constant tension

The Benefits of Constant Tension

Letoff	Drying Drums	Postcalender Pull Rolls	Cementer Pull Rolls	Windup
1. Compensation for elliptic or eccentric fabric rolls which produce tension variations that stretch fabric severely	1. Compensation for shrinkage or stretch 2. Elimination of loose wrinkles which would be cut by calender rolls	1. Compensation for shrinkage or stretch 2. Favorable influence on maintaining gauge	1. Compensation for shrinkage or stretch 2. Favorable influence on even distribution of cement	1. Elimination of loosely wound rolls which deform in storage 2. Elimination of tightly wound rolls where fabric sticks to liner in later operations

stantially more than what would be available from the main generator and a booster would have to be used to overcome this.

The power circuits for both the entry auxiliaries and the delivery auxiliaries are treated in the same manner. In either group the individual drives always operate together. They must be separated from the central auxiliaries and the calender because of the roll-changing requirements. They are stopped for roll changes while the calender is running, restarted, and then temporarily overspeeded to restore the amount of stock in the festoons to normal.

Calender Control

A simplified schematic diagram of the calender control circuit is shown in Figure 4. The electronic preamplifier makes use of vacuum tubes to provide excitation to the amplidyne that controls the generator field. This combination provides very accurate control of speed, preset speed, and what may be termed "timed acceleration."

So-called "timed acceleration" is simply a means for obtaining the kind of operation a motor-operated generator field rheostat furnishes but with more flexibility. It consists of a resistor–capacitor circuit in the electronic preamplifier arranged so that as the capacitor charges, the speed of the calender motor accelerates with it and as the capacitor discharges, the calender motor decelerates. The range of time provided is from 15 to 100 seconds and is readily adjustable by changing the amount of resistance. These time values represent total time from zero speed to the top speed of 70 yards per minute, or from the top speed down to zero speed. For speed changes of smaller value, such as threading speed to top speed, the time is proportionally less.

The timed acceleration circuit represents a very important operating feature in calender control as too rapid acceleration is quite undesirable. The auxiliaries associated with the calender train must follow whatever speed changes occur on

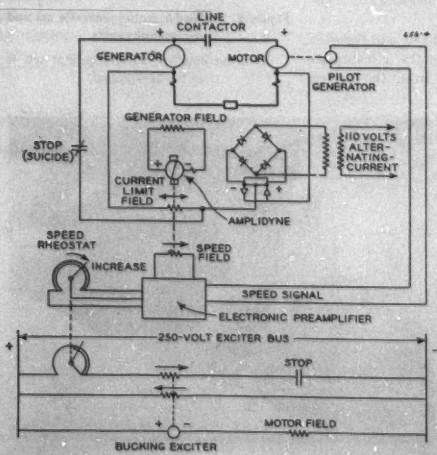

Figure 4 (left). Calender control circuit

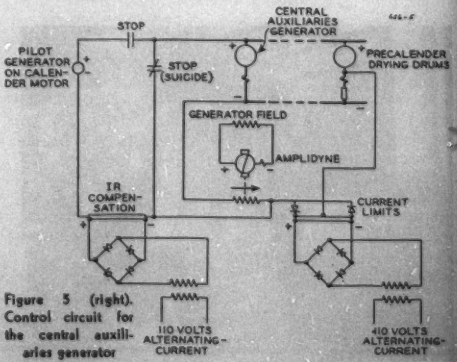

Figure 5 (right). Control circuit for the central auxiliaries generator

the calender itself. If these changes are rapid, excessive changes in tension are produced. Furthermore, the calender operators have no opportunity to adjust the calender roll screwdowns with rapid changes of speed to hold gauge.

In effect, this circuit provides an infinite number of speed points so that acceleration and deceleration are both very smooth.

The control also furnishes means for limiting both motoring and regenerative currents to values required either from the standpoint of performance or commutation. Under conditions of acceleration or normal deceleration, current limit is not necessary because of the timing circuit. It is provided only as a safety means. However, to meet the requirements of fast emergency stopping, regenerative current limit is an extremely important function.

When the stop button is pushed, the amplidyne exciting the generator is connected in a "suicide" circuit so that the generator voltage collapses rapidly. As the regenerative current from the motor to the generator reaches a value of approximately 200 per cent, the current limit circuit prevents the generator voltage from decaying at a rate faster than the decrease of the motor internal voltage with deceleration.

The regenerative current is held at the 200 per cent limit until the internal voltage of the motor, at about 5 per cent speed, no longer is able to overcome the *IR* drop of the armature loop circuit.

When stopping, full field is established in the motor as rapidly as possible. This is done to obtain maximum torque per ampere and a high rate of deceleration. The inductive lag of the motor field, which resists this change, is reduced materially by reversing the output of the bucking exciter and applying approximately twice normal voltage across the motor field.

Stopping performance is considerably better than that obtained by dynamic braking in conventional equipment operating from a constant potential d-c source. In contrast to a braking current of 200 per cent obtained by the amplidyne control with regenerative braking, the average current using dynamic braking is usually 30 or 40 per cent, with an initial peak of 200 per cent.

Control for Central Auxiliaries

In this group of auxiliaries, the motors on the post-tension rolls and the cementer pull rolls operate conventionally as motors, but the motor on the precalender drying drums operates as a braking generator.

The central auxiliaries generator is controlled by an amplidyne exciter, as shown in Figure 5. The control is arranged so that the voltage output of the generator is proportional to the speed of the calender motor, plus a fixed value for what we may call *IR* compensation. The speed-voltage component is established by taking a signal from the pilot generator on the calender motor. The motors on both the post-tension rolls and the cementer have substantially the same *IR* drop and the fixed voltage introduced for *IR* compensation is made equal to it. Hence, at any speed of the calender itself, the voltage available for these two motors will be very nearly equal to what they require for counterelectromotive force and full load current.

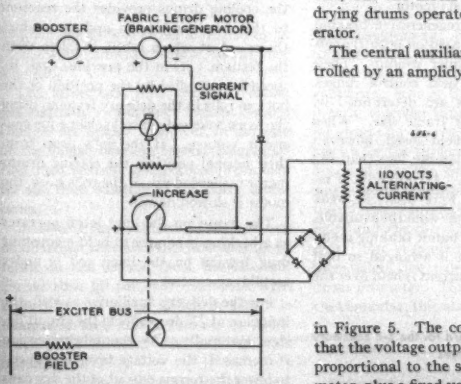

Figure 6. Control circuit for the fabric letoff motor and booster

Each of the three motors has an amplidyne exciter. For the two machines which actually are motoring, the amplidyne control is arranged to hold constant armature current. Hence, at the voltage established by the speed of the fabric, constant current is equivalent to constant horsepower input to the motors. Neglecting their internal losses, this is substantially constant horsepower output, or constant torque at any given speed. As the friction torque required by these auxiliaries is low and does not change much, most of the motor output goes into tension, and this will be substantially constant.

As the speed of the fabric is changed, the voltage level is readjusted proportionately. The horsepower input to the motors therefore is changed accordingly, and with armature current unchanged, constant tension is maintained over the speed range.

The amplidyne control for the drying drums motor operates in a somewhat different manner. Since it is regenerating, its internal voltage not only must be sufficient to overcome its internal *IR* drop, but also the *IR* compensation voltage, which is a component of the generator voltage. This is done easily at top speeds where a very small increase in flux provides a large increase in internal voltage. However, at one-tenth speed, the flux must be increased substantially. The flux variation from top speed to bottom speed is about two to one.

For constant tension, it is necessary to hold a constant torque output from this machine at any speed within the operating range. Thus, as the flux is increased, the regenerative current must be reduced. The amplidyne control is arranged to do just that. At any particular speed, it maintains the current output constant. If the speed is increased, the current also is increased to compensate for the decrease of flux. The converse is true when the speed is decreased. At one-tenth speed, where the flux is twice the value at top speed, the control holds a current equal to only one-half the value established at top speed.

When the "stop" button is pushed, the amplidyne control of the generator is reconnected in a "suicide" circuit. Current limit control is provided, using a signal proportional to the armature current of the drying drums motor.

When stopping, there is no control over the regenerative currents from either the post-tension rolls motor or the cementer pull rolls motor, as they have lower inertias than the drying drums motor and can decelerate with it without difficulty.

Control for Entry Auxiliaries

The fabric letoff operates as a braking generator, with an amplidyne exciter holding constant current to obtain substantially constant drag tension on the fabric (Figure 6). The pull rolls motor provides the necessary reaction to overcome this tension and determines the speed at which the fabric is taken from the letoff. It is controlled by regulating the generator voltage in accordance with

the position of the bottom rolls of the festoon. The rolls adjust the air gap of a solenoid, which controls an amplidyne used to excite the generator. If the rolls drop from their normal position, the pull rolls motor is slowed down, and if they raise, the motor is speeded up.

The motor on the liner windup operates as a motor and is under constant tension control, with an amplidyne exciter regulating its armature current.

The influence of *IR* drop, particularly at the lower speeds, has a material influence on the circuit designs. If the fabric tension is increased by strengthening the regenerative current from the fabric letoff motor, the voltage level on all motors is increased because the tension reaction must come from the pull rolls machine. This makes it more difficult for the letoff motor to regenerate.

To overcome this, a booster generator is used in series with the armature of the letoff motor. The voltage from the booster is of such a magnitude and direction that it not only compensates for the internal *IR* drop of the letoff motor, but also the rise in generator voltage, when the stock tension is increased.

As the pull rolls motor and the liner windup motor both are supplied from the same generator, a booster on the windup motor is unnecessary. However, these machines must be designed so that their internal *IR* drops are the same.

Current limit control for acceleration and deceleration is employed, using a current signal from the armature circuit of the pull rolls motor.

When speed is changed in either direction, the tension being used between the letoff and pull rolls is sufficiently high so that only small changes occur. However, this is not the case for the liner windup and a circuit is used for inertia compensation. When accelerating, it increases the regulated value of current to supply an accelerating component, and conversely, decreases it under deceleration.

To replace the festoon storage after a shutdown to change rolls, the entry auxiliaries are overspeeded by a maximum of 20 per cent with respect to the speed at which the fabric is being taken away from the festoon. This is accomplished automatically by the solenoid control.

When a stop is to be made, the generator amplidyne is reconnected in a "suicide" circuit with current limit control from the pull rolls motor.

Instead of using regenerative braking, dynamic braking is used on both the fabric letoff and the liner windup. These motors have wide field control ranges. Thus, their inertias are determined by their base speed, or frame size. When operating at weak field speed, however, the torque is considerably less than full field would provide. Accordingly, if regenerative braking were used, at weak field, insufficient torque would be available.

In view of this, dynamic braking is employed. The circuit is arranged so that constant armature current is held over the field control range. Thus, when operating at weak field, as deceleration occurs and the motor slows down, the field is strengthened so that the internal voltage of the motor is kept at a constant value. Once base speed is attained, the dynamic braking current, of course, decays with speed.

Both the liner windup motor and the stock letoff motor are extremely difficult to stop and several times normal current must be used in the dynamic braking circuit.

Figure 7. Control board for the a-c accessory drives

Control for Delivery Auxiliaries

The delivery auxiliaries group is quite similar to the entry auxiliaries. The fabric windup, in this case, operates as a motor, with amplidyne control maintaining constant winding tension. The motor on the cooling drums provides the reaction to this winding tension and determines the speed at which fabric is taken from the festoon. As in the previous case, its speed is controlled by the position of the bottom rolls in the delivery festoon, using the same solenoid control scheme for generator voltage. If the rolls drop from their normal position, the cooling drums motor is speeded up; if the rolls raise, the motor is slowed down.

The motor on the liner letoff operates as a braking generator to hold a constant drag tension on the liner and is under amplidyne control.

For the delivery auxiliaries as well, the influence of *IR* drop affects the circuit design materially. As the fabric tension is increased, the voltage level is reduced to lower the torque output of the dry cans motor. As a matter of fact, at very high values of fabric tension, this machine actually must regenerate as there is insufficient festoon weight and friction load in the cooling drums to provide the tension.

The decrease in voltage level, however, makes it more difficult for the stock windup motor to obtain motoring current. A booster is used, therefore, with this machine. The voltage from the booster consists of a component to overcome the internal *IR* drop of the windup motor, and also an additional voltage equivalent to the reduction in generator voltage with increases in tension.

The liner letoff motor, which operates as a braking generator, is provided also with a booster which compensates for the *IR* drop of the letoff motor and changes in the voltage level.

For current limit control, when accelerating or decelerating, a signal is taken from the armature circuit of the dry cans motor. This control operates as it did for the entry auxiliaries, adjusting the gener-

Figure 8. Main calender desk

ator voltage to hold either accelerating or decelerating current constant, as the case may be.

The fabric and liner tensions remain substantially constant when speed changes are made. However, in the case of the fabric windup, inertia compensation must be used, as explained previously for the liner windup on the entry auxiliaries.

Following the shutdown of the delivery auxiliaries for a roll change, the storage of fabric in the festoon must be removed. To do this, 20 per cent overspeed with respect to the speed at which fabric is being delivered to the festoon is available. The solenoid control does this automatically.

When a stop is to be made, the generator amplidyne is "suicided" and the current limit control from the cooling drums motor determines the rate of deceleration. Dynamic braking is used on both the fabric windup and the liner letoff for the same reasons that it was chosen for their counterparts in the entry group. Several times normal current must be used to stop these auxiliaries.

Co-ordination of A-C Accessory Drives

The driving motor of the large motor-generator set is a 450-horsepower unity power factor synchronous machine, supplied from a 2,300-volt source. A switchgear-type controller is furnished for this motor, suitably interlocked with the d-c control equipment in case of a loss of voltage, or an overcurrent indication.

There are also about 24 low voltage devices such as motors, solenoids, or valves, which operate from a 440-volt supply. These are controlled and interlocked with the d-c equipment. A load center type of control board, shown in Figure 7, is used.

The motors involved include those for ventilating fans in the cementer, cement pumps, calender lubricating pumps, water pumps for the cooling drums, feed conveyors for the rubber banks in the calender, and also the driving motors of the small motor-generator sets used for the train drive. Interlocking between these units and the d-c control is very important. For example, in case of a loss of lubrication, the calender must be shut down promptly. If ventilation is lost in the cementer, this also must be done.

Operation

To satisfy the operating requirements previously described, a substantial number of selector switches and pushbuttons is required. However, these are conveniently grouped in a main desk (Figure 8) located at the calender, an entry letoff desk, and a delivery windup desk. In addition, there is a small operator's panel located right next to the letoff and another at the windup. These contain the switches which are of immediate use to the operators when changing rolls. A considerable amount of precautionary interlocking is employed to avoid misoperation and mistakes on the part of the operators.

For normal running, once the calender train has been threaded, operation is actually simpler than with a conventional type of mechanical drive. The calender running speed, acceleration rate, and tensions are preadjusted, so that the operator only has to push a "Run" button and the entire train accelerates to the predetermined speed. This may be done only from one central point, the main desk.

On this desk also are located a recording and indicating tachometer calibrated in yards per minute, instruments for thickness gauge, and yardage counters which indicate the total yardage into and out of the train at the end of a day's operation. The master speed adjusting rheostat is also on this desk, but a speed limit rheostat which determines the maximum speed for any particular run is placed on the main control board so that it is accessible only to supervisors. Adjustment and indication of the current in both the drying drums motor and post-tension rolls motor are provided on the desk, so that the operator can control the precalender and postcalender tensions. Selector switches and pushbuttons for the roll screwdown motors and the necessary threading and jogging buttons are there as well.

The letoff and windup desks have the adjustments and instruments for the motors associated with them, as well as certain jogging and bypass buttons.

The entire train can be stopped from a number of places including several rope-operated safety switches. All stops are treated as emergency stops in order to bring the train down quickly, and give a constant check on stopping performance.

Changing Rolls at the Windup

When the operator observes from a yardage indicator on the windup desk that the fabric roll is nearly full, he places an operating switch in the "Change Rolls" position. This slows down all of the auxiliary drives associated with the delivery festoon to half speed. When the desired maximum roll diameter actually is reached, he moves the operating switch to the "Stop" position which quickly stops all of the delivery festoon auxiliaries. The calender in the meantime continues to run, filling the empty festoon.

As the delivery auxiliaries stop, a clamp roll, immediately above the windups, is set so that it holds the stock in place against the festoon weight when the operator cuts it. The cutting operation is done automatically by a "fly knife" which travels transversely across the stock.

After the cut has been made, the operator places a selector switch in position for the alternate windup. This windup previously had been operated by jogging so that a few turns of liner are wrapped around it from the liner letoff associated with it.

The operator then returns his operating switch to the "Change Rolls" position so that the alternate windup with the other delivery auxiliaries starts up. An air valve control device then actuates a small conveyor which transfers the leading end of the cut fabric from the first

windup to the one that now will be used. It puts it in such a position that it is caught automatically in the "bite" formed by the liner as it wraps around the roll.

After the stock has made several wraps around the roll with the liner, the operator puts his operating switch in the "Slack Takeup" position which automatically removes slack and establishes tension, with the delivery auxiliaries still operating at half speed. He then moves the operating switch to the "Normal" position and the delivery auxiliaries accelerate to a speed somewhat higher than that of the calender, depending upon how much storage must be removed from the festoon.

Changing Rolls at the Letoff

This operation is quite similar to that at the windup. The operating switch has the same positions. In the "Change Rolls" position the entry auxiliaries operate at half speed. In the "Stop" position a mechanical brake is set to hold the fabric against the weights of the festoon rolls when the fabric letoff no longer provides the necessary tension.

When the operator has spliced the trailing end of the stock going to the festoon to the leading end of the fabric from a new letoff roll, the "Slack Takeup" position automatically reverses the letoff and its associated liner windup to take up slack. This is very important because the splice is not strong and if slack were not eliminated, the resulting jerk at starting the entry auxiliaries might break the splice.

In the "Normal" position, the entry auxiliaries accelerate to some speed higher than that of the calender so that normal storage of fabric can be returned to the festoon.

Conclusion

It is expected that the automatic control, made possible by the use of individual electric drives, will result in a substantial improvement in the quality of the product. Regulated tensions should eliminate fabric that is stretched too much, or so slack that it wrinkles. This will reduce rejections and increase production.

The rubber industry deserves praise for pioneering this type of equipment and discarding the conventional. Processing techniques may benefit, not only in this industry but also in others, such as textiles, plastics, and photographic film where similar problems exist.

Reference

1. Continuous Processing for Automobile Tire Fabrics, G. E. Cassidy, W. A. Mostellar. AIEE Transactions, volume 58, 1939, May section, pages 218–23.

A New Crystal Channel Filter for Broad Band Carrier Systems

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Synopsis: A new crystal channel filter for use in broad band carrier telephone systems is described. It requires less than two-thirds as much mounting space as the earlier design and savings in materials and manufacturing effort are realized. These savings were made possible by assembling the four crystal units in one lattice-type filter section rather than two, resulting in a reduction in the number of component coils and capacitors.

CRYSTAL filters first were used commercially as channel selecting filters in a carrier system developed for use on cables.[1] Their use in that system permitted the placing of a large number of telephone channels close together in the frequency spectrum. The terminal equipment of the system was designed to provide a bank of 12 channels in a frequency band 48 kilocycles wide, suitable for any transmitting medium capable of providing this band width. Subsequent to its use on cable circuits, this 12-channel bank was applied to other new broad band carrier systems for use on open wire lines and on coaxial cables. The crystal filters used in this original bank were those described by C. E. Lane in 1938.[2]

As the demand for broad band carrier systems increased, a need developed for a channel filter which could be produced in relatively large quantities more economically than the original design. The type of design which seemed most promising was one which used a more compact configuration for the filter, thereby reducing the number of coils and capacitors required. However, this type of filter is critical of adjustment and the desired performance is realized only if the electrical characteristics of the component elements are maintained close to their theoretical values. This requires that the crystal units be adjusted precisely and that they retain their electrical characteristics accurately for variations in time and temperature.[3] As a step in this direction, the stability of performance of crystal units was improved by the development of the wire-supported mountings in place of the earlier clamp-type mountings, and the provision of hermetically sealed containers.[4] The use of this new type of crystal unit construction made it practical to provide the new filter design described in this paper. The four coils used in the old filter were replaced by two less expensive coils, and four of the capacitors were omitted in the new design. These changes and the resulting reduction in size made possible the saving of large quantities of materials and greatly reduced the required manufacturing effort.

A comparison of the size and internal appearance of this new filter (type 219) and the old filter (type 75) is shown in Figure 1. The new filter weighs less than half the old one and requires less than two-thirds as much mounting space. In order to utilize efficiently the size reduction of the filters they are assembled in a new design of terminal equipment. Figure 2 shows a typical office installation in which old and new type terminal equipments are mounted in adjacent bays. The 219-type filters appear in the equipment in the two bays on the right, whereas the 75-type are shown in the equipment on the left.

All 12 of these channel filters transmit the lower sidebands derived from the modulation of speech signals and carrier frequencies located 4 kilocycles apart in the range from 64 to 108 kilocycles. An insertion-loss frequency characteristic which applies to each of these filters is shown in Figure 3. This performance curve is very similar to that of the earlier channel filter, but the loss in the pass band is lower and the filter has sharper cutoffs than the earlier design.

Crystal filters usually are designed as lattice-type rather than ladder-type structures because of the greater flexibility afforded by the lattice design. For a lattice-type structure the functions for the propagation factor and characteristic impedance may be chosen independently as they involve only the quotient and product of the impedances or admittances of the series and diagonal branches.[5] The

Paper 46-26, recommended by the AIEE committee on communication for presentation at the AIEE winter convention, New York, N. Y., January 21–25, 1946. Manuscript submitted November 21, 1945; made available for printing December 1945.

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complexity of the branches of the lattice structure is dictated by the sharpness of the cutoff and the width of the pass band desired. The schematic circuit of the 219-type filter is shown in Figure 4. By relocating the shunt capacitances and series inductances as part of each lattice branch and replacing each crystal element by its equivalent network, an inductance and capacitance in series shunted by a second capacitance, the schematic of Figure 5 is obtained. The theoretical values of the elements shown in this schematic are derived from the following assumptions:

1. The location of the two cutoff frequencies.
2. The location of five frequencies of infinite attenuation.
3. The value of the impedance constant.
4. The coincidence between zeros and poles of the series and diagonal branches at the four critical frequencies occurring within the filter pass band.

Figure 6 shows the elements that comprise the filter. At the two ends are located the two air-core coils mounted in drawn copper cylinders. This coil is a duolateral type having a Q, that is, the ratio of reactance to effective resistance, of approximately 150 at the operating frequency. The same coil is used in each of the 12 filters. Because of the high coil impedance called for by the filter design, care is taken to make the parasitic capacitances between the windings and between the windings and the case as low as practicable. This is accomplished by winding the coil in four sections as shown in Figure 7. Such reduction in capacitances also results in improved stability of the coil and filter characteristics under service conditions.

Four resistances, two at each end of the filter, regulate the loss level in the pass band so that the band loss of each of the 12 filters is approximately the same. Fixed molded silvered mica and fixed and adjustable air capacitors are the remaining elements mounted on the upper side of the panel. The silvered mica capacitors and the two end adjustable air capacitors provide the shunt capacitances at the input and output of the lattice. The center adjustable capacitor is a differential air capacitor which, along with the two small fixed air capacitors, provides small capacitances across each of the four lattice branches. The four crystal plates, mounted in glass envelopes and assembled as a unit, form the basic structure of the lattice. Figure 8 shows one such group of four plates and illustrates how the 16 wires from the crystal units are connected to the terminals forming the four corners of the lattice. The main differences among the 12 channel filters are the differences in the dimensions of the crystal plates. The crystals are -18.5 degree X-cut longitudinal plates supported by fine wires located along their nodal lines. The mounting and fabrication of these crystal units has been covered very thoroughly in a recent paper by R. M. C. Greenidge.[6]

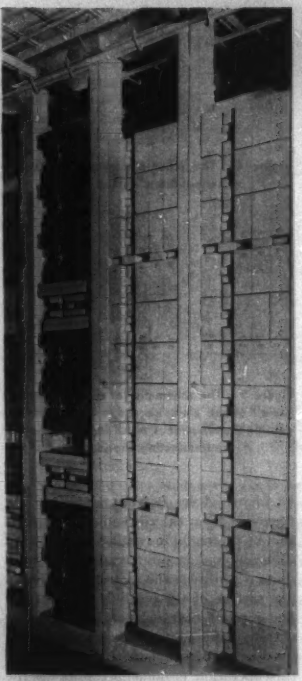


Figure 2. The 219-type filters form a part of the 12-channel banks on the right, whereas the 75-type filters are utilized in those on the left

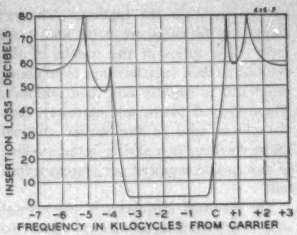


Figure 3. The insertion-loss frequency characteristics of the 12 filters are the same when plotted in cycles removed from the carrier frequencies

Figure 1. The 219-type filter requires less than two thirds of the mounting space and weighs less than half the 75-type filter

The length of a -18.5-degree plate in a quartz crystal unit is determined almost entirely by the frequency of resonance desired. The width and thickness are controlled mainly by the inductance. In addition to obtaining the desired resonant frequency and inductance it is essential that the strong secondary resonant frequency (this is an objectionable response) of each crystal unit be confined to a region that is not being used for the transmission of speech. There are such regions, each approximately 700 cycles wide, between the adjacent channel bands. The length, width, and thickness of the crystal plates then are determined discretely by the desired resonant frequency, inductance, and location of secondary response.

The equivalent inductances of the crystal units used in these 12 filters range in value from 38 henrys to 576 henrys. Even the four crystal units assembled in one filter cover a relatively wide range of inductance values. The ratio of the inductances of the two crystal units connected in parallel in the series branches o the lattice is five-to-one and in the diagonal branch crystal units is four-to-one. The crystal plates range in length from 1.66 inches for the lowest frequency unit

to 0.94 inch for the highest. The extremes in thickness are 0.019 and 0.085 inch. The ratios of the widths of the crystals to their lengths range from about one tenth to slightly less than one half. These crystal plates are narrower than the plates used in the earlier channel filters resulting in a saving in the amount of raw quartz required per system terminal.

The resonant frequency of the crystal unit is adjusted in an electric circuit to within seven to ten cycles of the desired frequency by grinding down the length of the plate. The inductance of the crystal unit is held to within three per cent of its nominal value by manufacturing tolerances on the fabrication of the plate. However, as shown later in the paper, this rather broad range of inductance values would permit a wide divergence in filter performance. In order to limit this range of performance the four crystal units used in any one filter are selected so as to have approximately equal departures in inductance from the nominal values. The magnitudes of their respective variations from a common percentage departure from nominal are plus or minus one half per cent for the two low inductance units and plus or minus one per cent for the two high inductance units.

In order to meet this close requirement on inductance grouping with the limited number of crystal units available, the inductances of a large percentage of the plates are adjusted in the manufacturing process. The inductances of all units are made to fall within one of two groups, each meeting the foregoing limits, one centered about the nominal value and the other two per cent above nominal. The inductance of a coated crystal plate may

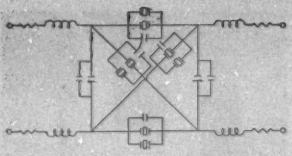


Figure 4. The schematic circuits of the 12 channel filters are the same

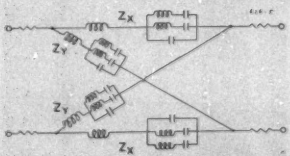


Figure 5. The schematic for design purposes has all of the elements within the lattice excepting the resistances which form a portion of the terminating impedances

be increased by isolating or effectively removing from the electric circuit a portion of the metallic coating. The procedure followed in the manufacture of the units is to divide the metallic coating on one surface of the plate by a transverse line located near one end of the plate thereby reducing the effective plated area by a small percentage. In manufacture this operation is done just prior to the assembly of the crystal plate in its cage.

These filters provide 50 to 60 decibels loss to all frequencies more than about 700 cycles from the edges of the pass band. To maintain this high loss in one lattice-type filter section necessitates a close impedance balance between the branches of the lattice. A plot of the reactance-frequency characteristics of the two branches of the lattice, Figure 9, helps to explain the transmission properties of the filter. Where the reactances Z_x and Z_y of the two branches are of opposite signs the filter is transmitting but where they are of like signs the filter attenuates. Figure 10 shows on an expanded scale the percentage difference between these two reactance curves in the attenuating region of the filter. Where this difference is zero the attenuation is infinite, or, in other words, a peak of attenuation is located at this frequency. There are four peaks of attenuation located at finite frequencies as shown by the points at which this difference curve crosses zero and also a peak of attenuation located at infinite frequency where the two reactance curves meet.

To obtain discrimination of approximately 60 decibels and maintain it over the anticipated life of the filter requires precise adjustment of the filter elements and the stable performance of these elements in service. Certain elements have greater effect on filter performance than others and hence greater precision of adjustment and more stable performance is required of them. An examination of the function of each of the various elements in shaping the two reactance curves Z_x and Z_y will reveal the elements in which the greatest precision of adjustment is required. Any small change in an element which causes similar changes in the two reactance curves without changing their relation to each other will have very little effect on the attenuation curve. But, any change in an element which changes one reactance curve with respect to the other will alter the filter performance greatly. Thus changes in the elements which appear in the series branches and not in the diagonal branches or which appear in the diagonal branches and not in the series are the ones that cause relative movement of the two reactance

Figure 6. The elements are assembled on a panel in much the same position as they are shown in the filter schematic

Figure 7. The coil winding is sectionalized to reduce the parasitic capacitances

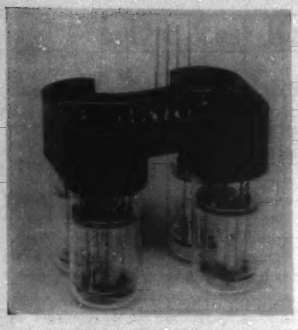


Figure 8. This crystal unit is a four-terminal lattice network comprised of four divided quartz plates and electrically providing two crystal elements in parallel in each branch of the lattice

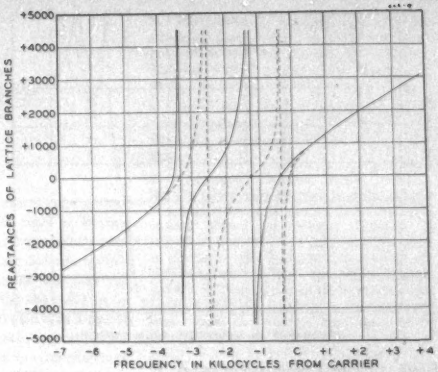


Figure 9. Where the reactances of the two branches of the lattice are of opposite signs the filter transmits and where they are of like signs the filter attenuates

curves. Hence it is the elements which appear within the lattice structure, that is, the four crystal units and the lattice of capacitances consisting of the differential air and fixed air capacitors, that require precise adjustment and stable performance.

In order to obtain uniform performance in the filters it is necessary to hold the resonant frequency and inductance of the crystal units within very narrow limits. For example, the solid curve of Figure 11 illustrates a normal transmission loss characteristic in which the elements are all at their nominal values. The two dotted curves illustrate the characteristics that result when the inductance values of the crystal units in either the series or diagonal branches depart from their nominal value by about one per cent. A negative departure in one pair of branches results in about the same effect in performance as a positive departure in the other pair. The two curves shown assume positive and negative departures for the inductances of one pair of branches. The selection and grouping of crystal units assembled in any one filter in relation to their inductance departures from nominal, as discussed earlier in this paper, restricts the variations in filter performance.

Departures of about ten cycles per second in the resonant frequencies of the crystal units of either series or diagonal branches will produce variations in discrimination of about the same type and magnitude as those illustrated in Figure 11 for departures in inductance. However, if all crystal units exhibit equal frequency departures, the entire transmission characteristic will be shifted by the frequency departure of the crystal units, and there will be little change in discrimination. For a 20-degree Fahrenheit change in temperature this frequency shift is approximately 0.03 per cent of the operating frequency.

The lattice of capacitances is balanced in the final adjustment of the filter by the tuning of the differential air capacitor. This adjustment moves one reactance curve with respect to the other to locate one of their crossings, and thus one peak frequency, at 600 cycles above the carrier frequency.

In the foregoing discussion the effect of dissipation in the elements forming the filter has been neglected. As there is some dissipation associated with each coil, capacitor, and crystal unit, the effect of each in turn will be considered. The dissipation associated with the coils may be considered as part of the terminating impedances and variation in this dissipation raises or lowers the loss level in the band of the filter without affecting the discrimination. Dissipation in the shunt capacitors at the input and output of the lattice produces similar effects on the filter. When these effects become too large, causing the loss in the pass band to fall outside the specified limit, the resistances at either end of the filter are changed in value to compensate for the change in dissipation.

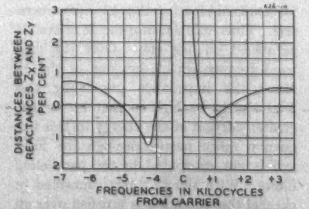
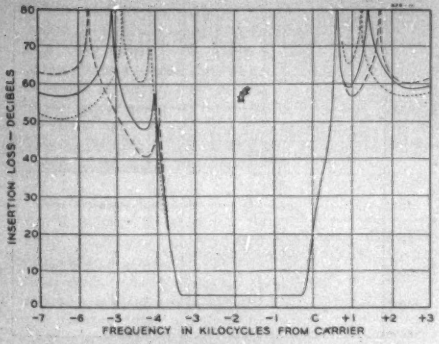


Figure 10. The two reactance curves cross at four frequencies which determine the location of the four attenuation peaks

The elements forming the branches of the lattice, that is, the crystal units and the capacitor lattice introduce very little dissipation. However, since unbalances in the dissipation associated with the lattice branches of the filter will degrade the filter performance to the same extent as reactance unbalances in these branches, extreme care must be exercised to keep the dissipation among these branches balanced. Instead of referring to the reactances of the branches of the lattice, Z_x and Z_y, it is more convenient in the following discussion to refer to their reciprocals, the susceptances B_x and B_y. Dissipation associated with these susceptances is expressed in terms of the conductances, G_x and G_y. To obtain a peak of attenuation in a lattice-type filter it is necessary to have a conductance balance as well as a susceptance balance of the series and diagonal branches of the lattice. Equal conductances across the series and diagonal branches of the lattice have the same effect as equal conductances across the input and output of the lattice. That is, they have the effect of raising the loss in the pass band of the filter slightly. However, an unbalance between the conductances of the series and diagonal branches of the lattice upsets the bridge balance at the filter peak frequencies. The effect of a slight unbalance is a reduction in the magnitude of the peak losses of the filter. As this unbalance is increased the filter peaks may disappear entirely even though there is a susceptance balance at the peak frequencies. This is illustrated by the curves in Figure 12. The solid line represents a normal transmission-loss characteristic of the 219AM filter, with carrier fre-



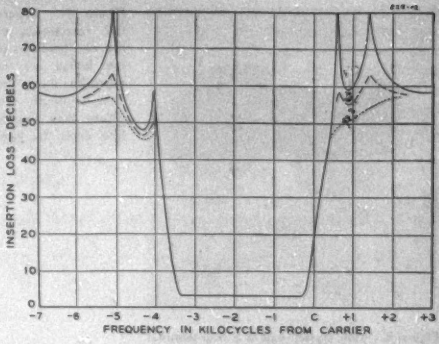


Figure 11. Precise cutting and adjustment of crystal units are required to obtain uniform filter performance

The foregoing effects were produced by inductance departures of one per cent from nominal of crystal units in either pair of lattice branches

Figure 12. To obtain high peak loss in a lattice-type filter the conductances and susceptances of the series and diagonal branches must be equal

The effects of differences of 0.010 and 0.030 micromho conductance in these branches are shown, respectively, by the dashed and dotted curves

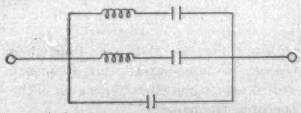


Figure 13. This two-terminal network is connected across the paralleled end of the filters to improve the transmission over the two end channels of the group of 12

quency at 108 kilocycles, in which there is a perfect balance of both the conductance and susceptance at the peak frequencies. The dashed and dotted lines show the effect of 0.010 and 0.030 micromho conductance unbalance, respectively. Greater amounts of conductance unbalance are required to produce these same effects in the lower frequency filters in inverse ratio to the square of the operating frequencies.

Even though the crystal plates are surrounded by dry air and enclosed in sealed glass containers it is still necessary to protect the filter against atmospheric conditions of high relative humidity. The dashed curve of Figure 12 shows the effect of 0.010 micromho conductance unbalance of the lattice. This unbalance is equivalent to 100 megohms insulation resistance. With clean parts and a relatively dry atmosphere insulation resistance many times as high as this can be maintained across the branches of the lattice. However, a trace of salt or other contamination across the terminals in the molded base of the crystal unit or across the ceramic in the air capacitors will make the insulation resistance highly sensitive to the moisture in the adjacent air. To guard against this condition of low insulation resistance, the following precautions are taken:

1. Where insulating materials are required within the lattice structure only homogeneous low-loss materials are used.
2. The insulating parts assembled in the filters are kept clean.
3. The filters are adjusted, tested, and sealed hermetically when surrounded by an atmosphere in which the relative humidity is not greater than 40 per cent.

In the construction of the filter the elements are mounted on the panel and wired as shown in Figure 6. This panel assembly with cover and end brackets attached is inserted in an adjusting shield through which the three capacitor adjustments are made. The resonant frequencies looking in either end of the filter are located where they should occur theoretically, by the adjustment of the two end air capacitors. The other adjustable air capacitor is used to locate a peak of attenuation at 600 cycles above the carrier frequency.

The function of the channel filters in service is to select the modulated electrical impulses from 12 subscribers' sets and combine them for transmission over the line, and at the receiving terminal to separate the various electrical impulses for transmission to the 12 subscribers' sets. Thus, in operation the 12 filters are paralleled on one end. Over the pass band frequencies of any one of the 12 filters the impedance paralleling this filter should be high so that by far the greater portion of the energy in this frequency range passes through the filter and is not dissipated in the paralleling filters. With the 12 filters connected in parallel this condition is satisfied over all channel bands excepting the two end channels. Good transmission is obtained over all channels by connecting a two terminal network, the schematic of which is shown in Figure 13, across the paralleled end of the filters.

The 219-type "Crystal Channel Filter" is the first commercial application of lattice-type filter circuits in which more than one crystal unit is used in each branch of the lattice. The use of this circuit reduces the number of component elements required in each filter and results in a saving in mounting space required. As these filters constitute a large portion of the broad band carrier terminal equipment this development has contributed to a considerable saving in office space. The labor required for producing these filters has been reduced by a third in comparison with that required for the earlier design. Also, substantial savings in the use of tin, nickel, molybdenum, brass, and raw quartz are realized.

References

1. Cable Carrier Telephone Terminals, R. W. Chestnut, L. M. Ilgenfritz, A. Konner. AIEE Transactions, volume 57, 1938, May section, pages 237–44.

2. Crystal Channel Filters for the Cable Carrier System, C. E. Lane. AIEE Transactions, volume 57, 1938, May section, pages 245–9.

3. Effects of Manufacturing Deviations on Crystal Units for Filters, A. R. D'heedene. *Bell System Technical Journal*, volume 23, July 1944, page 280.

4. The Mounting and Fabrication of Plated-Quartz Crystal Units, R. M. C. Greenidge. *Bell System Technical Journal*, volume 23, July 1944, page 234.

5. Electromechanical Transducers and Wave Filters (book), W. P. Mason. D. Van Nostrand Company, New York, N. Y., 1942.

6. See reference 4.

Die Cast Rotor Testing by Test Stator Method

P. H. TRICKEY
MEMBER AIEE

FOR some years now, it has been a common practice to die cast the squirrel cages of induction motor rotors. The die cast rotor has many advantages of simplicity, ruggedness, and durability as well as low cost. One feature of die castings is the tendency for all castings to have a perfect outside surface even though the interior may contain voids, blow holes, or porosity. This feature is an advantage when the appearance of the die cast article is of primary importance. However, in an electric rotor, it is a disadvantage as no visual inspection methods will disclose a faulty interior which may affect the electrical performance.

Since the conductivity of the best electrical materials such as copper and aluminum are affected by small amounts of impurities, there is always the possibility of low conductivity being introduced at some stage between ingot and final cast rotor. This defect also cannot be detected by visual inspection.

It is necessary, therefore, to have some means other than inspection for testing die cast rotors. Of course, one way of testing such rotors is to build them into complete motors and make thorough tests on the motors. Obviously, this has the great disadvantage of performing many expensive and time consuming operations before it is known that a rotor is defective. Sometimes also other variations in the completed motor make it very difficult to lay positively the cause of poor performance to the die cast rotor.

There are, of course, an infinite number of ways in which a rotor can be defective such as wrong laminations, core stack, skew, and shaft hole, but in general, if the resistance is correct, all other defects can be caught by inspection and gauging. Once in a great while open bars may get by a resistance test but except for rare cases a measurement of the average rotor resistance can be used to select the satisfactory rotors.

There are two common methods of measuring the effective secondary or rotor resistance of a squirrel-cage motor. One method obtains the rotor resistance from readings of slip and secondary copper loss. This has certain definite usefulness for polyphase motors, but has the disadvantage of requiring the rotor to be finished completely and tested in a motor with bearings. The other method involves a measurement of the impedance of the motor with rotor held stationary. From this impedance, the rotor resistance is separated by calculation from the stator resistance and reactance. By taking full advantage of the locked impedance method which requires no rotation, bearings, or line up variations, a very satisfactory method of testing die cast rotors may be devised.

Paper 46-64, recommended by the AIEE committee on electric machinery and technical program for presentation at the AIEE winter convention, New York, N. Y., January 21-25, 1946. Manuscript submitted August 25, 1945; made available for printing December 11, 1945.

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Test Stator for Testing Die Cast Rotors

It would be possible to use a normal stator and, without end covers or bearings, make an impedance test for rotor resistance of a die cast rotor. Special care would have to be taken in testing, as the stator being designed for normal operation at full speed would draw heavy currents and get very hot with rotor standing still. The rotor also would get hot. Correction of resistance measurements for temperature would be subject to error as the temperature not only would be high, but also changing rapidly.

To overcome these and other difficulties, stators for testing die cast rotors are made of special construction and proportions.

1. The stator slots are made much larger than normal, to give 8 to 10 times the normal winding area. This in itself reduces the stator temperature and the amount of primary resistance to be subtracted from the total resistance. It gives a stator much larger in diameter than normal, but the additional size and cost do no harm for a test device.

2. The number of effective turns are usually much greater than the normal stator to give about half the normal flux densities. This keeps the iron loss of the large stator down, and reduces the effect of saturation.

3. Since under locked impedance conditions the phases operate independently, only one phase is necessary for the stator winding.

4. The inside diameter usually is made slightly larger than normal, just big enough to admit rotor cores as they come from die casting before the outside diameter is turned to final size. If the stator has open or partially open slots and the mould allows aluminum to flow over the unfinished surface, it may be necessary to remove this excess aluminum to obtain accurate readings. If it is desired to test soldered or brazed copper or brass rotors in such a stator, it may be necessary to trim off the excess solder or brazing material in order to get the rotor into the stator. Otherwise, the air gap may have to be increased too much and errors are introduced.

5. In general, the width or stack of the test stator is made as narrow as the shortest rotor likely to be tested in quantity, and used for all rotors of that diameter. There is very little error introduced when the rotor is longer than the stator, but if the rotor is shorter, new calibration curves may have to be made because of the change in air gap area.

6. Stators usually are mounted vertically and the windings given thick protective coatings to minimize the damage of rotors continually striking against the stators during insertion. In spite of all precautions, the windings ultimately become short circuited or the laminations badly worn and hammered together at the air gap. If production testing is to be continuous and shutdowns for repair avoided, it is well to have spare stators available for immediate replacement. If it is expected that the windings of individual stators will vary in resistance, it may be desirable to add a rheostat to the circuit which may be adjusted as each new stator is installed thus keeping the same value of total resistance in the primary circuit and eliminating the necessity of new calibration curves for each new stator.

7. In general a single phase concentric winding is used with the turns distributed sinusoidally. A typical core lamination is shown in Figure 7.

Testing Circuit

The equivalent circuit of each phase of an induction motor under locked rotor condition is as shown in Figure 1. For

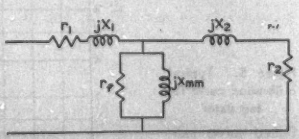


Figure 1. Equivalent circuit of induction motor with rotor locked

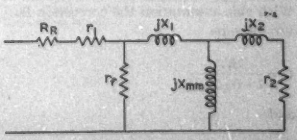


Figure 2. Equivalent circuit used in analyzing tests of die cast rotors

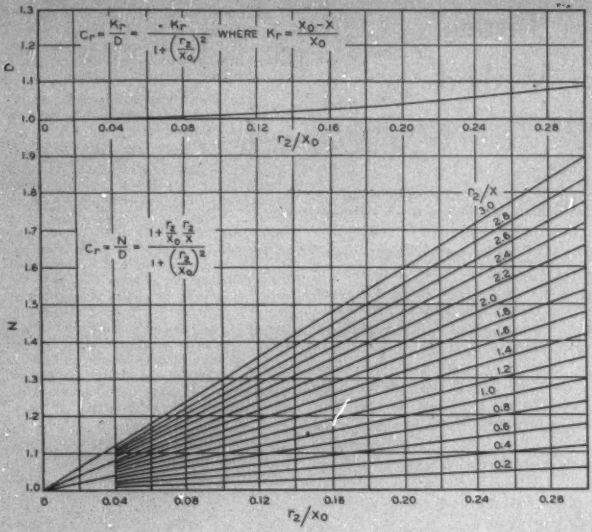


Figure 3 (left). Locked rotor impedance

Single-phase and polyphase induction motors

where

$X_o = X_{mm} + x_1 = X_{mm} + x_2$ = ideal short-circuit reactance

$$K_r = \left\{\frac{X_{mm}}{X_{mm}+x_1}\right\}^2 = \left\{\frac{X_{mm}}{X_{mm}+x_2}\right\}^2 = \left\{\frac{X_{mm}}{X_o}\right\}^2 = \frac{X_o - X}{X_o}$$

Figure 3 is sometimes a convenient aid in using these formulas.

Referring to Figure 2, if it is assumed that the current in the iron branch has negligible effect on the magnitude of the total line current, the following expressions may be used:

$E = IZ_L$ where $Z_L = \sqrt{R_L^2 + X_L^2}$, $X_L = XC_R$

and

$R_L = R_R + r_1 + r_2 C_r$ (R_R = rheostat resistance)

Watts input = $I^2 R_L$ + iron loss

A convenient calculation form is shown in Figure 4. It is customary to calculate a complete curve of watts versus r_2 and to use this curve in setting test limits for production test. Such a curve is shown in Figure 5.

Determination of Circuit Constants

In order to use the form shown in Figure 4, it is necessary to know the circuit constants r_1, X, X_o, and the iron loss.

r_1 can be measured easily by resistance bridge.

X can be obtained from a locked rotor reading using a typical rotor, preferably of low resistance. It is usually necessary to have tests with finished and unfinished rotors so that rotors can be tested later under either condition. Usually the same values of test constants can be used re-

the purpose of rotor testing, it is satisfactory to assume the iron loss branch to be in shunt across the input as shown in Figure 2. The impedance of the network beyond the iron loss branch has been shown by C. G. Veinott to be:

$$Z_L = R_L + jX_L = (r_1 + r_2 C_r) + jXC_R$$

where

X = ideal short-circuit reactance

$$= x_1 + x_2 \frac{X_{mm}}{x_2 + X_{mm}}$$

$$C_r = \frac{X_{mm}^2}{(x_2 + X_{mm})^2 + r_2^2}$$

$$C_R = \frac{1 + \{(x_1 + X_{mm})/X\}\{r_2/(x_2 + X_{mm})\}^2}{1 + \{r_2/(x_2 + X_{mm})\}^2}$$

r_1 = primary resistance
r_2 = secondary resistance referred to primary
x_1 = primary leakage reactance
x_2 = secondary leakage reactance referred to primary
X_{mm} = mutual or magnetizing reactance

For the purpose of rotor testing, it is satisfactory to assume primary and secondary leakage reactances to be equal. With this assumption the correction factors become

$$C_r = \frac{K_r}{1 + (r_2/X_o)^2}$$

and

$$C_R = \frac{1 + (r_2/X)(r_2/X_o)}{1 + (r_2/X_o)^2}$$

I	2.5	2.5
r_2	10	50
r_2/X_0	0.0388	0.194
r_2/X	0.252	1.26
D (FIG. 3)	1.001	1.04
N (FIG. 3)	1.013	1.245
$C_R = N/D$	1.011	1.197
$X_L = X C_R$	40.2	47.5
$C_r = K_r/D$	0.845	0.815
$r_2 C_r$	8.45	40.7
r_1	2.10	2.10
R_R	0.10	0.10
$R_L = r_1 + R_R + r_2 C_r$	10.65	42.9
$Z_L = \sqrt{R_L^2 + X_L^2}$	41.5	64
$E = I Z_L$	103.9	160
IRON LOSS	7.1	16.9
$I^2 R_L$	66.5	268
WATTS INPUT = IRON LOSS + $I^2 R_L$	73.6	284.9

Figure 4. Calculation sheet for die cast rotor calibration curves

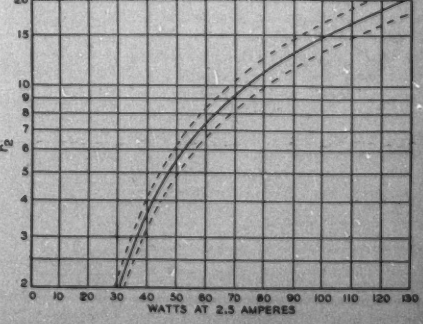


Figure 5. Typical calibration curve for test stator

Dotted curves indicate upper and lower watt limits

1	NO LOAD (DUMMY ROTOR) VOLTS	84
2	NO LOAD (DUMMY ROTOR) AMPS I_0	0.469
3	NO LOAD (DUMMY ROTOR) WATTS	5.458
4	PRIMARY RESISTANCE AFTER NO LOAD READING	2.08
5	$I_0^2 r_1 = (2)^2 (4)$	0.458
6	IRON LOSS = (3) − (5)	5.00
7	$X_0 = Z_0 = E/I_0 = (1)/(2)$	179
8	LOCKED ROTOR VOLTS	84
9	LOCKED ROTOR AMPERES	2.5
10	LOCKED ROTOR WATTS	63.5
11	IRON LOSS	5.0
12	NET WATTS	58.5
13	R = TOTAL EFFECTIVE RESISTANCE = (12)/(9)²	9.35
14	PRIMARY RESISTANCE AFTER LOCKED READING	2.10
15	P = (13) − (14)	7.25
16	$Z_L = (8)/(9)$	33.6
17	$Q = \sqrt{(16)^2 - (13)^2}$	32.2
18	$X_0 - Q = (7) - (17)$	146.8
19	r_1 = PRIMARY RESISTANCE COLD (@ 25°C)	2.08
20	$r_2 = (15)\ (7)/(18)$	8.76
21	$r_2/X_0 = (20)/(7)$	0.049
22	$1 + (r_2/X_0)^2 = 1 + (21)^2$	1.024
23	$Q[1 + (r_2/X_0)^2] = (17) \times (22)$	32.3
24	$r_2\ r_2/X_0 = (20) \times (21)$	0.43
25	X = (23) − (24)	31.9

Figure 6. Calculation sheet used for determining circuit constants

gardless of core stack, but it is well to try different stacks just to be sure. For the purpose of analyzing the locked rotor tests, we can assume the equivalent circuit of Figure 2. The locked impedance of the network beyond the iron loss branch has been shown to be

$$Z_L = [r_1 + P] + jQ$$

where $P = r_2 C_r$ and $Q = XC_R$

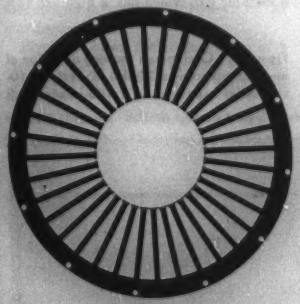
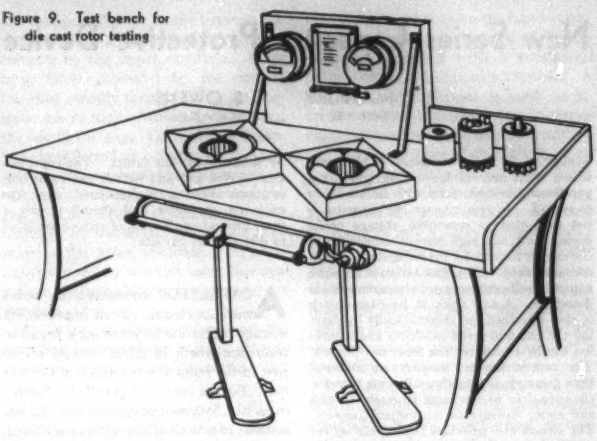


Figure 7. Typical test stator lamination for die cast rotor test

Figure 9. Test bench for die cast rotor testing



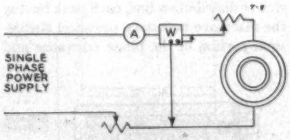


Figure 8. Wiring diagram for die cast rotor test circuit

Assuming that the current in the iron loss branch has a negligible effect on the magnitude of the total line current, we find

$$Z_L = E/I_L,\ R_L = [\text{watts input} - \text{iron loss}]/I_L^2$$

$$P = R_L - r_1 \text{ and } Q = \sqrt{Z_L^2 - R_L^2}$$

Mr. Veinott has shown that

$$r_2 = \frac{PX_o}{X_o - Q}$$

where

$X_o = X_m + x_1$ = ideal open circuit reactance

He also has shown that

$$Q = XC_R = X\frac{1 + (r_2/X)(r_2/X_o)}{1 + (r_2/X_o)^2}$$

Transposing and solving for X

$$X[1 + (r_2/X)(r_2/X_o)] = Q[1 + (r_2/X_o)^2]$$

$$X + r_2(r_2/X_o) = Q[1 + (r_2/X_o)^2]$$

$$X = Q[1 + (r_2/X_o)^2] - r_2(r_2/X_o)$$

X_o and the iron loss for this type of test stator can be obtained from input readings using a rotor similar to a typical rotor except with no squirrel cage at all.

Under this condition, it can be assumed that

$$X_o = Z_o = E/I_o$$

and that the

Iron loss = input − copper loss

In this case also, it is usually desirable to have tests with both finished and unfinished rotor diameters. It is desirable to take the dummy rotor tests over a fairly wide range of voltages to be sure to cover any case of high or low rotor resistance in later tests. A convenient form for analyzing these tests is shown in Figure 6.

References

1. Segregation of Losses in Single-Phase Induction Motors, C. G. Veinott. AIEE Transactions, volume 54, 1935, pages 1032–6.

2. Discussion by P. H. Trickey and author's closure of Segregation of Losses in Single-Phase Induction Motors, C. G. Veinott.

3. Single-Phase Induction Motors, W. J. Branson. AIEE Transactions, volume 21, 1912, pages 1749–87.

4. Starting Windings for Single-Phase Induction Motors, C. G. Veinott. AIEE Transactions, volume 63, 1944, pages 288–94.

5. Induction Motor Resistance Ring Width, P. H. Trickey. AIEE Transactions, volume 55, 1936, pages 144–50.

New Series Capacitor Protective Device

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Synopsis: A series capacitor is best protected from overvoltage during fault by a gap having low arc drop with no tendency to cut off. In this manner the capacitor is not subjected to repetitive voltage peaks during fault, and high current oscillations in the circuit formed by the capacitor and gap are minimized. A special design of graphite gap with self-centering arc characteristics is described. A new type of by-pass switch is also described for automatically by-passing the gap and series capacitor and removing the by-pass after the fault has cleared. The switch shown provides an inherent time delay on closing thus allowing time for the capacitor to discharge through the gap and avoid damage to the switch contacts. The switch also provides time delay on reopening thus eliminating the necessity for a holding means which has been a problem always with magnetic contactors in this application. The motive power for closing the switch is derived from a sealed bellows using high resistance metal and containing a volatile liquid. The passage of current through the bellows changes the vapor pressure and furnishes the forces required to operate the switch. A device of this type is not subject to damage by steep wave front surges associated with the discharge of the capacitor through the protective gap, nor is it damaged by intermittent line faults. The combination of this gap and switch has many advantages over a conventional gap and magnetic contactor and should permit a more general application of series capacitors to distribution circuits.

A CAPACITOR connected in series with an electric circuit improves its voltage regulation by inserting a negative reactance which in effect cancels all or part of the inductive reactance of the circuit. Such a capacitor is called a "series capacitor." A series capacitor installation consists of a bank of capacitors connected in series with each phase of a transmission or distribution line, each bank having the reactance necessary to cancel the desired portion of the phase reactance and designed to handle the maximum continuous and momentary line currents.

Capacitors may be subjected for brief periods to twice their rated voltage without damage to the dielectric; therefore, series capacitors may be allowed to handle momentary currents which are twice their continuous current rating. However, in most circuits to which series capacitors are applied the currents which flow during fault conditions are considerably more than twice the maximum working current. For this reason it is necessary either to use capacitors with a continuous current rating equal to one half the maximum current which may flow during a fault or to use a voltage limiting device.

For a given reactance the cost of capacitors increases approximately as the square of the rated voltage so that usually it is much more economical to use capacitors whose rating is based on the working current and limit the voltage which can appear across their terminals by means of auxiliary apparatus.

Protective Gaps

The device used to protect a series capacitor during fault conditions must not allow the capacitor voltage to rise above twice the rated value even for a short time. Thus, it must function to by-pass the capacitor during the first half cycle of fault current. A gap is the only device which meets this requirement effectively.

The fundamental protected series capacitor circuit consists of a series capacitor shunted with a gap. If, however, this is a metallic gap which has a high arc volt

Paper 46-45, recommended by the AIEE committee on protective devices for presentation at the AIEE winter convention, New York, N. Y., January 21–25, 1946. Manuscript submitted October 29, 1945; made available for printing December 13, 1945.

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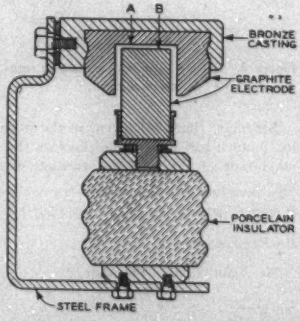


Figure 2. Cross section of new gap

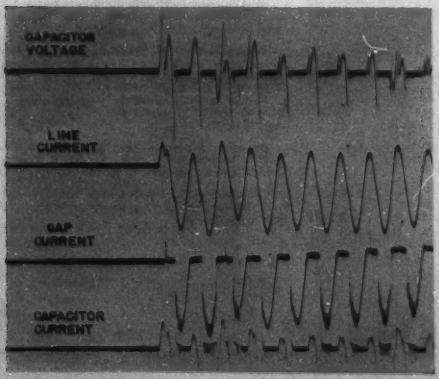


Figure 1. Oscillogram showing operation of a conventional gap protecting a 33-ohm, 60-cycle, 1,410-volt series capacitor on a 100-ampere fault

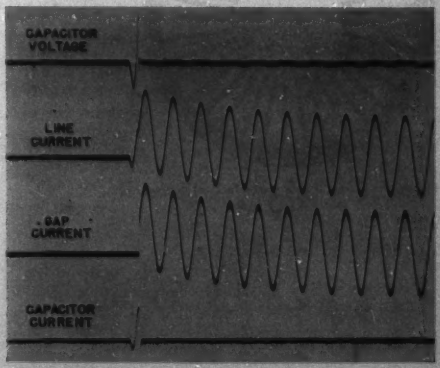


Figure 3. Oscillogram showing operation of new gap protecting a 33-ohm 60-cycle 1,410-volt series capacitor on a 100-ampere fault

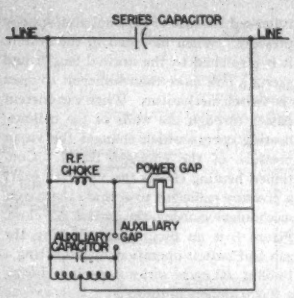


Figure 4. Series capacitor protective device for low voltage capacitors

age and a restriking arc, the series capacitor will be subjected to high currents while the arc exists in the gap. Figure 1 shows an oscillogram made of the current in a 33-ohm, 60-cycle series capacitor with a shunt gap set to break down at 3,000 volts. The gap electrodes were made of brass. The normal current of 43 amperes was increased to 100 amperes. The oscillogram shows the presence of high currents in the capacitor after the gap breakdown occurred. Such high currents cause heating of the capacitor and may cause serious damage.

The use of a gap having special graphite electrodes gives a low arc voltage and limits the current flowing in the series capacitor leads to a low value. Even with graphite electrodes, however, the arc will be moved out of the space between the electrodes by magnetic forces, thermal air currents, and random air currents unless special precautions are taken in the gap design.

Figure 2 shows the cross section of a special type of gap the authors have developed to insure a stable arc with a low arc voltage. The arc occurs between the surfaces *A* and *B* and is shielded from air currents by the upper electrode. Magnetic forces produced by the current traveling radially through the upper electrode are in such a direction as to keep the arc in the gap. Gaps of this design have been tested at currents up to 5,000 amperes for one second and sustained no damage. The arc remained between the gap faces at all currents, and there was no tendency for the arc to wander down the sides of the lower electrode. Figure 3 shows the results of a test using this new gap on the same circuit as that used for Figure 1.

As the spacing of a gap is decreased, the variation in breakdown voltage on successive operations becomes greater. For dependable operation a gap should be adjusted to break down at not less than 3,000 volts. Since the gap must function dependably at no more than twice the rated capacitor voltage, it cannot be used to protect a capacitor rated at less than 1,500 volts unless an auxiliary means is provided to ionize the gap when the capacitor voltage reaches twice the rated value.

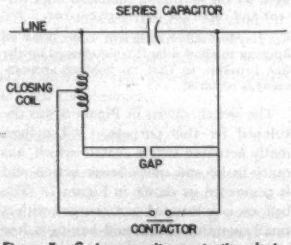


Figure 5. Series capacitor protective device with magnetic contactor to extinguish arc in the gap

Figure 4 shows a diagram of a gap-protected capacitor with a continuous voltage rating of less than 1,500 volts. A step-up autotransformer is used to increase a voltage obtained across the series capacitor to a level such that the auxiliary gap will break down when the voltage on the series capacitor is twice the rated value. The breakdown of the auxiliary gap allows the small auxiliary capacitor to discharge into a radio frequency choke which is in series with the main power gap. This discharge causes a high frequency voltage to appear across the choke. Since the series capacitor has a low impedance at this frequency, the voltage appears across the power gap causing it to break down and pass power current.

A simple gap-protected series capacitor is a satisfactory installation provided no fault is of sufficient duration that the heat generated by the arc will damage the gap, and provided the arc in the gap will go out when the line current drops to normal. Such conditions may exist on low voltage circuits. Usually, however, some special means must be employed to extinguish the arc in the gap.

Magnetic Contactors for By-Passing

Series capacitor protective devices made in the past have utilized gap current

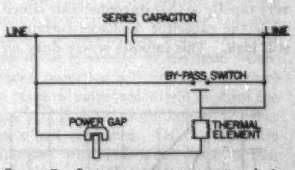
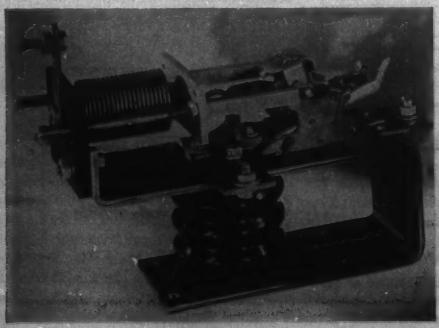
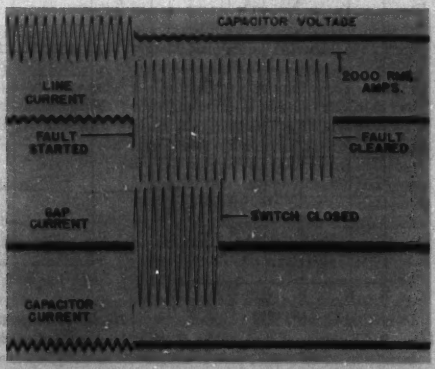


Figure 7. Series capacitor protective device using thermal switch

Figure 6 (below). Bellows operated toggle switch

Figure 8 (right). Operation of series capacitor protector using bellows operated switch





to initiate the closing of a magnetic contactor which by-passes the capacitor and gap to extinguish the arc. Such an arrangement is shown in Figure 5. The capacitor closing coil is placed in series with the gap so that when the gap breaks down the current flowing through the gap will cause the contactor to close. The contacts are connected to shunt the gap and all but a small portion of the closing coil. The number of turns remaining in the circuit is sufficient to cause the contacts to remain closed until the current in the line drops to normal. Thus, the arc exists in the gap only for the time required for the contactor to close, and the contactor shunts the capacitor for the duration of the fault.

The magnetic contactor provides adequate protection of the gap in a gap-protected series capacitor; however, a special and expensive contactor must be designed and built for each application. The size of the operating coil must be adjusted for each equipment so that the contactor will pick up at twice the rated capacitor current and drop out when the current drops to the rated value. The coil must be designed to withstand the steep wave front surge imposed upon it when the gap breaks down and the stored energy of the capacitor is discharged into the coil. In addition to stressing the coil, this surge also causes the contactor to accelerate very rapidly so that its contacts are closed while the capacitor discharge current is still high. This imposes severe duty on the contacts, and they must be carefully designed to prevent welding or excessive burning.

New By-Passing Switch

To overcome the difficulties encountered in the use of magnetic contactors, the authors set about to design a new type of by-pass switch to meet the following requirements:

1. It must close rapidly enough to protect the gap from overheating during any fault up to 2,500 amperes.

2. It should have sufficient time delay on closing in order that any capacitor bank up to 180 kva at 230 to 2,400 volts would be substantially discharged through the gap before the contacts engaged.

3. The motor element must not be damaged by the maximum combined fault current and capacitor discharge current.

4. It must have sufficient time delay on opening to allow a fault to be cleared by the line breakers so that no holding arrangement is required.

The switch shown in Figure 6 was developed for this purpose. It is a thermally actuated toggle switch which has quick-make and quick-break action and is connected as shown in Figure 7. The bellows is evacuated and charged with a small quantity of a liquid having a low vapor pressure at any ambient temperature which may be encountered in service. At such temperature the bellows remains collapsed because of external atmospheric pressure. When mounted in the switch, it is stretched to the normal length and exerts a pull more than sufficient to open the switch mechanism. When gap current passes through the walls of the bellows, heating occurs which changes the vapor pressure of the enclosed liquid. Continued heating causes the vapor to exert a pressure sufficient to actuate the toggle mechanism causing the switch to close. Figure 8 is an oscillogram showing the gap and switch operation in protecting a 16-ohm, 60-cycle series capacitor during a 2,000 ampere fault.

The closing of the switch by-passes the entire series capacitor and thus terminates the flow of gap current and allows the bellows to start cooling. Cooling causes the vapor to recondense, and the resulting differential pressure reopens the switch and restores the series capacitor to service.

The gap may be allowed to reach a temperature of 250 degrees centigrade with no risk of damage. Figure 9 shows the time-current characteristics of the gap shown in Figure 2 based on an attained temperature of 250 degrees centigrade on the top casting and shows also the time required for the switch to close for the same currents. From this it is seen that the switch meets the first requirement of protecting the gap for all currents in the operating range. The tests from which these data were procured were made at an ambient of 25 degrees centigrade; however, the gap and switch combination is temperature compensating, and adequate protection is obtained throughout the operating temperature range. At high ambient temperatures the gap reaches the maximum permissible temperature in a shorter time, but the switch closes more rapidly. At low ambients the switch operates more slowly, but the gap requires longer to reach the temperature limit. Temperatures below the freezing point of the enclosed liquid do not damage the bellows because of its flexible nature and because the quantity of liquid is very

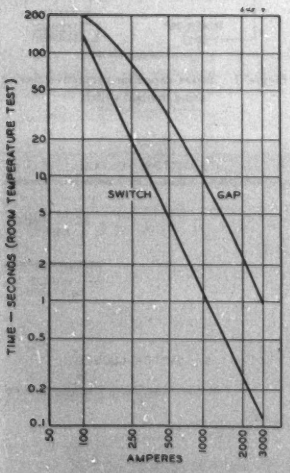


Figure 9. Time-current characteristic of gap and switch

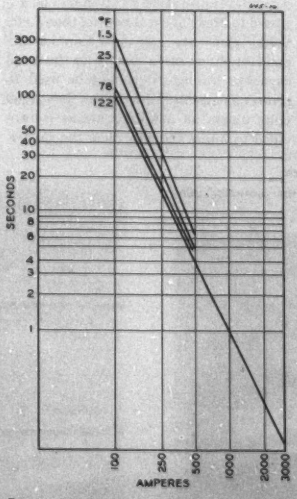


Figure 10. Variation in closing time of bellows operated switch with variations in ambient temperature

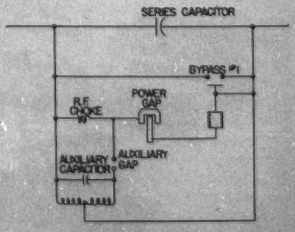


Figure 11. Low voltage series capacitor protective device

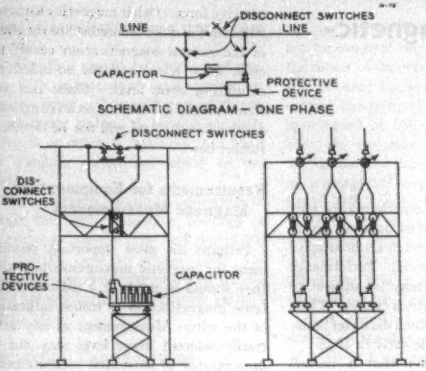


Figure 12 (left). Typical series capacitor installation

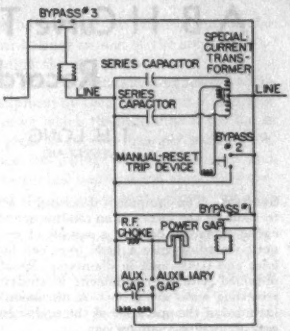


Figure 13 (right). Series capacitor with short circuit, overload, and dielectric failure protection

small. Operations at ambients below freezing do not take appreciably longer than those above freezing since the heat of fusion of the liquid is small compared to the total heat input required to raise the bellows to the operating temperature. The operating time of the switch for various ambients is shown in Figure 10.

The motor element in the new switch is essentially self-protecting since the switch operates to stop the current flow in the bellows when it reaches a certain temperature. High currents simply cause the switch to operate more quickly. The switch shown has been tested with fault currents of 2,500 amperes and capacitor discharge currents of 100,000 amperes and sustained no damage.

The opening time of the switch varies from two to five minutes over the ambient temperature range of −20 degrees centigrade to +50 degrees centigrade. Thus, any fault will be cleared by the line breaker before the switch opens to restore the capacitor to service. An arcing ground on the system cannot cause operation of the switch more often than once every two minutes so that heating in the capacitor caused by discharge through the gap cannot be cumulative and cause damage.

Method of Installation

Figure 7 is the diagram of a high voltage (above 1,500 volts) series capacitor with short circuit protection. Figure 11 shows the low voltage equipment. In either case the complete assembly of equipment for each phase is mounted on a platform which is insulated from ground for the line-to-ground voltage as shown in Figure 12. Outdoor type capacitor units are used, and the protective equipment is housed in a weatherproof steel housing with one entrance bushing. A stud on the housing serves as the other terminal. Disconnect switches are provided to bypass and isolate the capacitor for inspection and maintenance.

Operating Limits

During momentary overloads, such as might be caused by motor starting or the operation of a resistance-welding machine, the series capacitor rated current may be exceeded, and it is not intended that the short circuit protective device should operate at such times. The breakdown voltage of the protective gap is subject to variation with temperature, humidity, condition of electrode surfaces, and rate of rise of the applied voltage. To allow for these variations, the gap is set positively to break down at 200 per cent of the rated voltages and never to break down at 150 per cent of the rated voltage. Therefore, it is important that the momentary current peaks never exceed 150 per cent of the continuous current rating of the capacitor. In some cases the current peaks will exceed considerably the normal sustained current. In these cases it is necessary to use a capacitor with a sufficiently high current rating that it will never be exceeded by more than 50 per cent, even though the capacitor will run most of the time with less than rated current.

Other Types of Protection

A series capacitor will be damaged by continuous operation at more than 110 per cent of its rated current. The short-circuit protective device may not function at less than 200 per cent of rated current; therefore, it is sometimes desirable to provide overload as well as short-circuit protection. The overload protective device should have an inverse time-current characteristic which can be coordinated with that of the capacitor to allow momentary but not continuous overloads. The bellows operated switch is ideal for this purpose. It is necessary only to connect a bellows of the proper current rating in series with the capacitor and to connect the switch to shunt the capacitor and bellows.

Still another type of protection that is sometimes used for series capacitors is dielectric failure protection. This is a means of detecting a failure in the working insulation of a capacitor unit in a capacitor assembly. In an unfused capacitor bank a short-circuited capacitor unit may sustain an internal arc which will cause gas to be generated in the unit. Continued operation will cause the pressure to reach a value which will rupture the case and possibly cause damage to other units and equipment. If the units are equipped with individual fuses, a fuse operation to remove a faulty unit increases the reactance of the bank and continued operation at the rated current of the original bank will subject the remaining units to overvoltage. The by-pass switch used in a protective device for dielectric failure protection is spring biased to the closed position and latched in the open position. A magnetic device is used to trip the latch when the currents become unequal in two equal branches of the capacitor bank. Each phase of the series capacitor bank is divided into two equal branches and connected so that the two branch currents pass in opposite directions through one winding of a special current transformer. No voltage is induced in the secondary winding until the two currents become unequal as a result of a short circuit in one of the capacitor units or a removal of one or more units by operation of individual fuses.

Figure 13 shows the diagram of a series

A B–H Curve Tracer for Magnetic-Recording Wire

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Synopsis: The equipment described is able to show on the screen of an oscilloscope the cyclic hysteresis loop of a sample of magnetic-recording wire a little over one inch long and 0.004 inch in diameter. Results obtained with the equipment in studying recording wires are given. A discussion is included of the operation of the equipment, and of possible modifications.

IN EXPERIMENTAL study of the performance of any particular type of recording or playback head in relation to magnetic-wire recording it becomes evident that there are at least two variables. One of these, and frequently the most serious, is the condition of the head as influenced by accumulations of dirt. The dirt that accumulates in such a head is usually magnetic, but it is probable that any kind of dirt is almost equally bad on account of the separation it causes between the wire and the pole pieces. Magnetic dirt has the additional disadvantage of causing a shunting effect on the gap. The second variable is the magnetic character of the wire itself.

It is a matter of experience that with suitable recording and playback heads the performance of a wire recording system is stable to within about 0.5 decibel for short lengths of wire. For frequencies above 2,500 cycles the performance may be subject to variations as great as 15 decibels in playing through a 1 hour spool of wire at 2 feet per second. Performance at lower frequencies may be subject to roughly one-third as much change. These figures apply to 0.004-inch diameter stainless steel wire available early in 1945.

It is known further that a normal change in the condition of the head will account for only a small part of the change in low frequency performance but that it may account for all of the change observed at high frequencies. This situation makes it important to be able to separate the variables of head condition and wire magnetic characteristic in order to find out what actually is happening. This requires special equipment for expediently measuring the magnetic characteristics of the recording wire.

The characteristics obviously of interest in a recording wire that is to be used as a permanent magnet are retentivity and coercive force. Other magnetic characteristics that may be of interest are the shape of the normal magnetization curve, the erase noise level, and the so-called d-c saturation noise level. These last two items usually are studied on a record-and-playback setup and will not be discussed further here.

Paper 46-30, recommended by the AIEE committee on communication for presentation at the AIEE winter convention, New York, N. Y., January 21–25, 1946. Manuscript submitted November 8, 1945; made available for printing December 26, 1945.

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Requirements for Equipment for Magnetic Measurements

Perhaps the most important requirement for magnetic measurements is that they should be made at a sufficiently intense magnetization to insure saturation of the wire. Measurement at any arbitrarily selected lower level may not be proportional to saturated measurements and in extreme cases will give little idea of the actual magnetic property of the wire. It originally was estimated that 1,500 ampere turns per inch would be necessary for the saturation of any wire. Subsequent experience has indicated that this is satisfactory for any wire suitable for magnetic recording with present head designs but that wire can be produced that requires more than 2,500 ampere turns per inch for saturation.

A requirement of almost equal importance is that the equipment should be able to operate continuously and indicate continuously the magnetic retentivity and coercive force of the wire as it runs through the equipment at a speed comparable to recording speed. The resolving power of the equipment should correspond to something on the order of 0.1 second playing time. There seem to be no variations in performance of an undesirable nature or magnitude that are of shorter duration than perhaps one-half second. If there were shorter transients, they could be studied best by oscillographic methods on a record-and-playback system which has a resolving power of a few thousandths of one inch.

Considerations of magnetizing coil design suggest the desirability of operating at a low audio frequency, perhaps several hundred cycles. A secondary consideration pointing in the same direction is the possibility of winding the detector coil on a stainless steel (nonmagnetic) tube.

It occasionally may be desirable to make rather accurate measurements at very low inductions, such as 100 lines per square inch. In order to avoid compromising the design as far as more normal use at much higher flux densities is concerned, it may be desirable to provide for measurement in such cases on a small bundle of wires. An example of this use would be the getting of that part of the

capacitor having short circuit, overload, and dielectric failure protection. Actually, overload and dielectric failure protection are seldom needed on distribution circuit series capacitors. These capacitors are usually selected on the basis of the maximum expected line currents, and these currents are not likely to be continuously exceeded because other equipment such as transformers would be damaged. When the units are applied in this manner and are properly protected against damage from short circuits, they seldom fail in service.

Conclusions

A graphite gap designed to hold the arc in a relatively fixed position provides the most effective protection for a series capacitor because it does not permit recurring rises in voltage on the capacitor during a fault. It can be designed to handle the fault current without being damaged and without serious changes in the breakdown characteristics.

A thermally operated by-pass switch of the type described provides an economical and effective means of extinguishing the arc in a series capacitor protective gap. The bellows operating element has a negligible inductance and is not damaged by the steep wave front surge of the capacitor discharge. The time delay on closing relieves the contacts of handling capacitor discharge current. The time delay on opening eliminates the need for a holding mechanism.

The thermal switch has an inverse time-current characteristic which makes it ideal for overload protection of series capacitors.

normal magnetization curve that is near the origin.

Calibration should be simple and precise with independent adjustments for coercive force and retentivity and should be relatively stable. A permissible drift might be as much as 5 per cent per hour. An absolute calibration would be desirable.

The equipment should be adjustable to obtain full scale retentivity readings at several convenient values between 10,000 and 100,000 lines per square inch. Adjustment also should be provided for full scale ampere turns per inch from perhaps 100 to 3,000.

Theoretical Considerations

The practicability of the use of the oscilloscope in obtaining hysteresis loop information on small punched washers of magnetic material has been demonstrated by Adler.[1] It would seem that something of the same technique should be applicable to the present problem. It hardly would be practicable to form the recorder wire into a loop to apply Adler's technique directly. Such a loop would require several turns to minimize end effect; and very high magnetizing currents would be required since the recording wire is actually a very efficient permanent magnet material.

An alternative is to run a straight wire through a magnetizing coil. The magnetizing force near the axis of a magnetizing coil of practical proportions will not be constant but will increase toward the center of the coil. Most of the change will be near the ends, and, if only the central one-third of the magnetizing coil is occupied by the detector and balance coils, the variation actually encountered will amount to only a few per cent, and an average value may be satisfactorily used; this is subject to limitations imposed by end effect. If the end effect is spread out over a length of the order of 100 times the wire diameter, it should not affect the results appreciably, and this expectation has been realized.

It is clear that, since operation is required on the flux contained in one piece of 0.004-inch diameter wire, a great many turns will be required in the detector coil through which the wire will run. It is further evident that a very substantial part of the flux through this coil will be flux outside of the wire and in air. For instance, if the inside diameter of the winding is 0.312 inch and the radial thickness of the winding is neglected, the ratio of the areas of air and iron included by the coil will be about 6,000. It will be necessary to exclude the influence of this air flux from the measurements, since it would mask completely the flux being measured. This is reasonably simple to do with a balance coil having a product of turns times area slightly greater than the detector coil and located along side of the detector coil within the magnetizing coil. A potentiometer adjustment can be used for the adjusement of the final balance as one of the steps in calibrating the equipment.

A definite limitation is imposed on the equipment by the requirement of handling wire for which the maximum induction is as great as 100,000 lines per square inch, since the voltage from the balance and detector coil combination must not overload the amplifiers that precede the integrating circuit.

This voltage prior to the integrating circuit is a very peaked wave, so that a fairly wide range of frequency must be handled without appreciable distortion, and what is perhaps more important, without appreciable relative phase shift between the various harmonic components at any point in the circuit. This will require the use of unusually large capacitors on the screen grids, and the elimination of cathode by-pass capacitors with a corresponding material loss in amplifier gain.

An interesting theoretical question is an appropriate design for an air core magnetizing coil to provide 1,500 ampere turns per inch continuously at say a maximum frequency of 500 cycles. It is known[2] that for a coil wound from round or square wire, and having proportions suited to the present problem, if the eddy current loss increases the effective resistance by more than about 50 per cent, the total loss will be reduced by winding with smaller wire to the same total turns and axial coil length. This makes it ap-

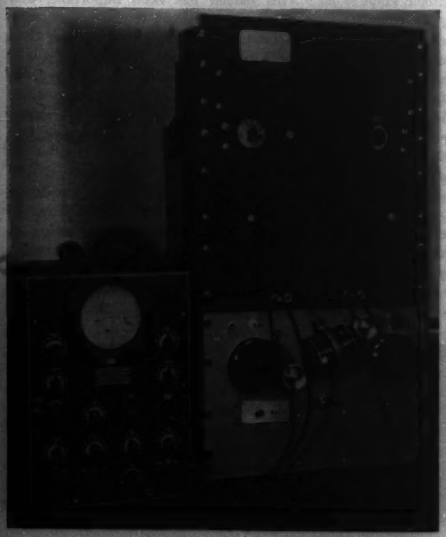
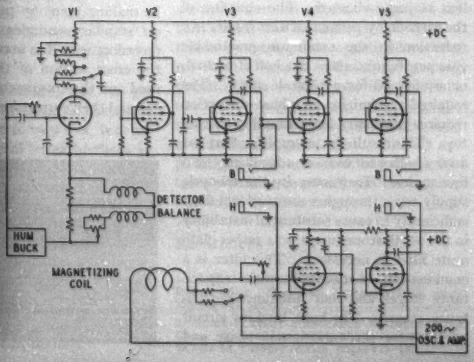


Figure 1 (left). Equipment for continuous magnetic measurements on magnetic-recorder wire

Figure 2 (below). Simplified schematic diagram of B–H curve tracer



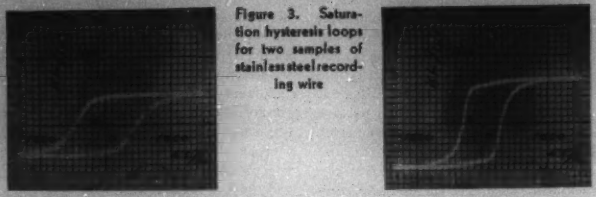


Figure 3. Saturation hysteresis loops for two samples of stainless steel recording wire

pear that for a radial winding depth of 1.25 inches the maximum practicable round wire size will be about 0.040 inch. The maximum practicable wire size will be roughly proportional to the reciprocal of the radial depth of the winding.

B–H Curve Tracer

The equipment as finally developed for the continuous measurement of retentivity and coercive force of moving or stationary samples of magnetic recording wire is shown in Figure 1. The lower section is occupied by the wire handling equipment and the magnetizing coil. Behind this unit on the relay rack is the power supply for the power amplifier that energizes the magnetizing coil at the finally selected frequency of 200 cycles. This power amplifier is at the top of the rack. In between there is a 200-cycle oscillator, an integrating circuit for the induction channel and associated amplifier, an amplifier for the magnetization channel, and the controls associated with these items. The equipment is self contained except for the oscilloscope and includes sufficient amplification for 20-volt output signals in both channels.

Figure 2 is a simplified schematic diagram in which certain standard items are designated simply by blocks. The resistance coupled amplifiers are modified from strictly conventional circuits to meet the special requirements of the present problem as just indicated. The omission of the cathode by-pass capacitors results in a reduction in the maximum practicable gain per stage to about one half of normal, or around 50 for a pentode stage. The required minimizing of phase distortion requires unusually large coupling capacitors. This results in an amplifier that has a very high gain even at a frequency of a few cycles. Transients in the 60-cycle supply come through a conventional filter sufficiently to cause substantial instability in the oscilloscope image, so a rather elaborate filter is necessary. This filter is a combination of two inductance–capacitance stages and four resistance–capacitance stages. The hum bucking circuit provides for the variation in phase and magnitude of a small inserted 60-cycle voltage and uses a capacitance–resistance phase split for the phase variation.

The afore-mentioned difficulties are increased by the necessity of using an integrating circuit in the induction channel of the amplifier, identified as B at the output jacks. This integrating circuit is, in effect, a resistance and capacitance in series that are so proportioned as to have a time constant on the order of 100 times the length of a half cycle. The resistance involved is the load resistance of amplifier $V2$ in parallel with the plate resistance of that amplifier, and the capacitance is connected from amplifier plate to ground.

In spite of the various steps taken to minimize phase distortion, a prohibitive amount remains, and this has been corrected to a tolerable value by the use of the resistance–capacitance network shown at the input to each of the channels. The adjustment of the phase correction network in the induction channel varies the position of the nearly vertical lines of the hysteresis loop, and in the proper operating range of this adjustment there is no other pronounced change in the hysteresis loop seen on the screen of the oscilloscope. This fact seems to preclude the expedient arriving at what might be called an absolute calibration of the system. Calibration against standard samples that have been measured by a point by point method is an easy way out after the standard samples have been measured. In making point by point measurements on standard samples of stainless steel recording wire it is necessary to calculate the cross section of the bundle of wire used and the cross section of the detector coil and then correct for the air flux. This correction amounts to about 10 per cent of the coercive force, when measurements are made on a ring sample.

Results Obtained With the B–H Curve Tracer

The advantages of being able to arrive quickly at the magnetic characteristics of short samples are too obvious to require further comment. The fact that these measurements are subject to an absolute error that may be as large as 10 per cent is not a serious handicap. The relative error is substantially less and depends only on the accuracy to which the image on the oscilloscope screen can be measured, on the accuracy with which the wire diameter can be measured (this influences retentivity only), and on the linearity of the oscilloscope. Figure 3 shows saturation hysteresis loops for two different samples of stainless steel wire, and Figure 4 shows two hysteresis loops taken on a single sample of wire about a foot apart; the difference may be due to the second loop's being in a part of the wire that had been welded at an earlier stage in the drawing. The change between these two loops was fairly gradual, and several half-pound spools were run through to find such a case.

When this project was started it was believed that the most important use of the equipment would be continuous measurements to determine the uniformity of the magnetic characteristics of a recording wire from one end of the spool to the other. This indeed has been important, and Figure 5 shows the retentivity and coercive force plotted against winding time for a constant spool speed that gave a nominal wire speed of 5 feet per second. The variations are of sufficient magnitude to account for several decibels of variation in the low frequency playback, but they are definitely not sufficient to account for the magnitude of frequently encountered variations in high frequency performance. The variations shown seem to be typical of current production of stainless steel wire (as of November 1945).

In the earliest use of this equipment for continuous measurements on running

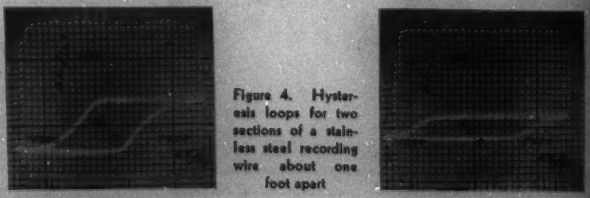


Figure 4. Hysteresis loops for two sections of a stainless steel recording wire about one foot apart

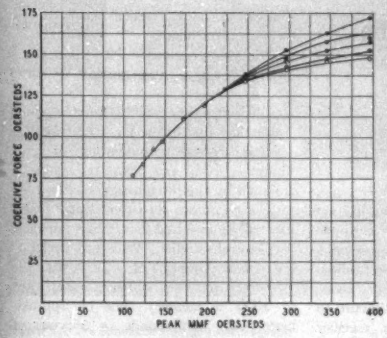


Figure 6A (left). Coercive force versus magnetization for several values of tension

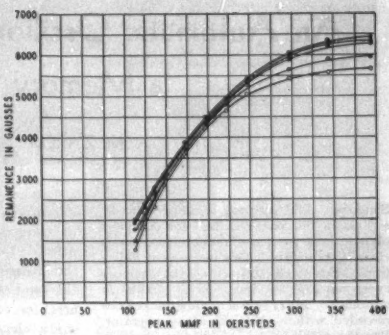


Figure 6B (right). Retentivity versus magnetization for several values of tension

Both parts are for stainless steel wire of 0.004-inch diameter. Tension varied from 0 to 2 pounds in half-pound steps, maximum tension at top

wire, a small pulsation of the hysteresis loop on the oscilloscope screen was observed. This amounted to only a few per cent of the intercepts on the B and H axes but seemed to be associated with the motion of the wire. It was found that this was caused by something analogous to magnetostriction. Small variations in tension that accompany the motion of the wire influence the magnetic properties of the wire to an appreciable extent.

A study of this effect was made in various wires to find out what the magnitude

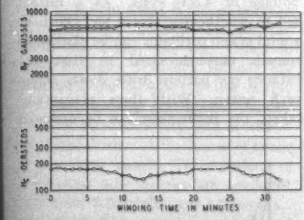


Figure 5. Retentivity and coercive force plotted against running time for a one-half pound spool of 0.004-inch diameter wire

Nominal running speed was 5 feet per second

might be and how it varied between samples. Figures 6A and 6B show characteristic results in which coercive force and retentivity are plotted against peak magnetizing force for various values of tension. In general an increase in tension always is accompanied by an increase of coercive force, and may be accompanied by either an increase or decrease in retentivity. The magnitude of the affect for a change in tension from zero to two pounds varies from 0 to 12 per cent for coercive force, and from 0 to 50 per cent for retentivity.

These stated values apply to the working range of magnetizations, and some wires do not exhibit either effect appreciably in this range, although it is evident above this range.

The B–H curve tracer, which might be more conveniently called a magnetoscope, also is useful in determining normal magnetization curves of recording wire. It seems necessary in this case to use a

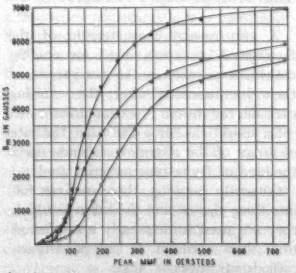


Figure 7. Normal induction curves for three samples of stainless steel wire

●—H_c 150, B_r 5,900
◐—H_c 185, B_r 5,400
○—H_c 250, B_r 4,800

point by point procedure, and, to get good detail at the bottom of the curve where the induction is very low, it is expedient to use several wires (perhaps as many as 10), but such curves can be obtained in about 5 or 10 minutes after the equipment has been calibrated. It usually will be expedient to measure the magnetizing force on a voltmeter connected across a resistance in series with the magnetizing coil and to read the induction on the screen of the oscilloscope. Figure 8 is a sample of normal induction curves obtained in this manner.

Conclusions

The necessity and adequacy of the magnetoscope as a development tool in experimental work on wire recording have been demonstrated. It would seem that the magnetoscope would be equally useful in control work, if the advantages of stainless steel wire are to be fully realized.

The utility of the magnetoscope is by no means limited to the field that has been explored in some detail in this paper. For instance it might be possible to use the magnetostrictive characteristic of a magnetic material to get a direct and almost instantaneous measure of the tension in the material.

The account that has been given has been limited to a measuring device in which the end effect (or return magnetic circuit) could be safely neglected. This is not a limitation inherent in the device. In the present form of the equipment the detector coil is somewhat sensitive to magnetic material closely adjacent to the magnetizing coil. This is associated with the energy loss so caused and the consequent lag between flux and current. It is probable that an external magnetic return circuit can be employed in spite of this by energizing the magnetization channel from a search coil and integrating circuit. This would make it possible to use such equipment in measuring the magnetic characteristics of a single strip of transformer grade alloy. In such applications a detector coil of only a few turns would be required, and the balance coil would be unnecessary.

References

1. B-H Curve Tracer for Lamination Samples, Robert Adler, *Electronics*, November 1943, pages 128–31, 314, 316–17.

2. Eddy-Current Resistance of Multilayer Coils, T. H. Long, AIEE Transactions, 1945, volume 64, October section, pages 712–18.

An Automatic Oscillograph With a Memory

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Synopsis: The memory oscillograph described in this paper is used for obtaining photographic records of randomly occurring electric transients. This instrument differs from other oscillographs of the memory type[1,2] in that its operation is completely automatic. Forty sets of oscillograms can be recorded without the aid of an operator. Because of this feature, such an oscillograph may be used for monitoring electrical systems in which sporadic circuit disturbances are to be studied. The unit consists essentially of three cathode-ray tubes with associated power supply, a saw-tooth oscillator to provide the horizontal time axis, amplifiers for the vertical deflection circuits, a beam blanking circuit, and an automatic camera. When the memory oscillograph is in operation, the cathode ray tubes are continuously excited. The vertical deflection circuits of the tubes are connected to the voltages to be investigated, and each tube screen carries a cathode-ray pattern characteristic of the voltage applied to its vertical deflection plates. Upon the occurrence of a transient pulse, the camera shutter is released and the electronic beams of the cathode ray tubes are interrupted. The camera then records the persistence of fluorescence, which is characteristic of the material used on the tube screens. In this way a record is obtained of electric events that occurred previous to the opening of the shutter. To insure successful operation, the component parts of the automatic memory oscillograph must be electrically co-ordinated and controlled. The sequence of functions performed by a control circuit for this purpose is described. Photographic records of transients which may arise during the operation of a mercury-arc polyphase inverter are included.

IN CONNECTION WITH research and development work on mercury-arc power converters, it is frequently necessary to study electric transients which occur at irregular intervals. Particular attention has been directed to the investigation of factors which encourage faulty operation. Not all of these factors are known and those that are known are not understood entirely. It is not a simple matter to obtain information concerning the initiation of transients. The random character of backfire phenomena in rectifiers, for example, makes it difficult to study electrical conditions in rectifier circuits immediately preceding backfire. Yet such a study is of prime importance if we are to learn more about the manner in which such faults occur.

The cathode ray memory oscillograph is an ideal instrument for this purpose. It can be made to provide a record of electric conditions previous to the occurrence of a transient as well as of the transient itself. The heart of this instrument is the cathode ray tube.

The Cathode-Ray-Tube Screen

A very useful characteristic of the fluorescent materials used for coating cathode ray tubes is the persistence of their luminescence after the exciting cathode ray beam is extinguished. All other conditions being the same, the rate of decay of the afterglow depends upon the kind of fluorescent material used.

Generally speaking, these coatings fall into three classes, and the tubes in which they are used consequently are referred to as short, medium, or long persistence cathode ray tubes.

Figure 1 illustrates in a general way the relative brightness retained for three different types of cathode ray tubes as a function of time. Curve *A* is characteristic of the short-persistence type P5 tube. The screen material used for this tube is an efficient emitter of light, and fluoresces in the blue range. The relative brightness falls to ten per cent in approximately 10^{-5} second. This rapid decay of brightness limits the use of these tubes in a memory oscillograph. Screens of this type find an important application when moving film recording is to be done. Due to the very short persistence, fogging of the film is kept to a minimum.

The medium-persistence P1 tube has a screen characteristic like that given by curve *B*. The relative brightness of such a screen falls to ten per cent in about 20 milliseconds. Most of the radiant energy of the P1 screen occurs in the yellow-green region.

The long-persistence P2 screen has a brightness-time curve similar to curve *C*. At voltages below 5 kv, the photographic efficiency for this tube is much lower than that of the P5 or P1 tubes.[3]

After careful consideration of tube characteristics and the requirements imposed by the intended application, the type P1 medium-persistence tube generally will be preferred for ordinary memory oscillograph studies. With an accelerating anode potential of 3,750 volts, the P1 screen provides sufficient after glow to allow a memory time of approximately 100 milliseconds, or 6 cycles of a 60 cycle a-c wave. By increasing the anode potential to 4,500 volts the memory time may be elevated substantially. However, because the use of beams of very high intensity has a markedly adverse effect on screen life, and since a cathode ray pattern of one type or another is on the tube screen continually, it is a matter of economics to avoid the use of very high intensities when they really are not required. For this reason an anode accelerating potential of 3,750 volts is desirable for normal operation. In anticipation of occasions when greater memory time may be required, provision may be made to allow the use of a tube voltage of 4,500 volts. As a further aid to lengthening screen life, the horizontal sweep oscillator can be allowed to remain unsynchronized so that the cathode ray pattern drifts slowly across each screen. With these precautions taken, the instrument can be operated

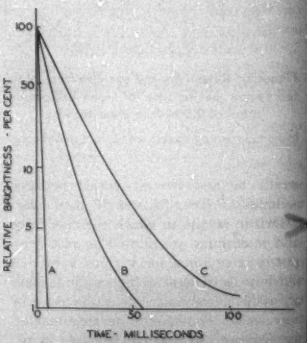

Figure 1. Curves illustrating typical variations in relative brightness as a function of time for three types of cathode-ray-tube screens

A—Short persistence
B—Medium persistence
C—Long persistence

Paper 46-67, recommended by the AIEE committee on instruments and measurements for presentation at the AIEE winter convention, New York, N. Y., January 21-25, 1946. Manuscript submitted October 29, 1945; made available for printing December 17, 1945.

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The author acknowledges the assistance of W. Richter and his associates at the Allis-Chalmers Manufacturing Company in the design of the instrument described here.

Figure 2. The automatic memory oscillograph

The automatic camera, the cathode-ray-tube unit, and the horizontal and vertical deflection control unit are shown

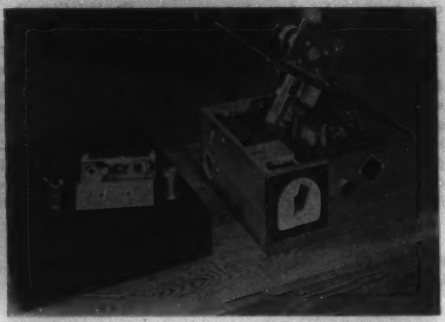


Figure 3. The automatic camera unit open to view

The camera and film loading cartridge are shown at the left

continuously 24 hours a day, with tube replacements required about once every five months. Tubes removed from the memory oscillograph, of course, will still be usable for ordinary cathode ray work.

Description of the Oscillograph Unit

Figure 2 is a picture of the automatic memory oscillograph. In normal operation a light-tight shield is placed between the camera lens and the cathode ray tubes. The lower tube unit shown in Figure 2 houses 3 5-inch cathode ray tubes with the necessary power supply and beam blanking equipment. Adjustments for focus, intensity, and accelerating potential are made by means of knobs on the front panel. Three values of accelerating tube voltage are available: 3,000 volts, 3,750 volts, and 4,500 volts.

Beam blanking may be accomplished in a variety of ways. If a trigger circuit[4] of the Eccles-Jordan[5] type is used, the output of this circuit is arranged so that the control grids of the cathode ray tubes will suddenly be made negative with respect to their cathodes when the circuit is tripped. Tripping may be accomplished by a voltage pulse of either positive or negative polarity. The pulse required is supplied by a control circuit which is actuated by the transient to be studied. Provision for adjusting the time delay between the opening of the shutter and the operation of the beam blanking circuit is contained in the control circuit. With such an arrangement, if the duration of the transient is not too great, it is possible to obtain a picture of the electrical conditions before, during, and after the occurrence of the transient. Information concerning conditions existing after the occurrence of a transient will be obtained at the expense of "memory time." However, situations may arise where such knowledge is desired.

The upper unit shown in Figure 2 contains the sweep oscillator for the horizontal timing wave and three sets of amplifiers for the vertical deflection plates of the cathode ray tubes. Each tube has its own 2-stage resistance-coupled amplifier. These amplifiers have a frequency response which is essentially flat up to 30,000 cycles per second.

The saw-tooth oscillator which provides the timing axis is common for all three cathode ray tubes. Simultaneous events therefore appear at the same relative location on all three tubes. Should the occasion demand it, the tubes may be operated with separate timing axes. This is done by means of convenient connections located on the rear panel of the tube unit. To aid in aligning electric events occurring at the same time, arrangement is made for simultaneously marking the traces on all three screens.

The usual means are provided for the adjustment of the vertical and horizontal gain as well as the vertical and horizontal positioning of the pattern for each tube. The saw-tooth oscillator may be interlocked with the frequency of the circuit being investigated, with a 60-cycle voltage, or with any outside alternating voltage.

The camera unit is shown in Figure 3. In addition to a lens and shutter, it contains a motor for automatically winding the photographic film and for closing the shutter after a picture has been taken. A step-type relay is included for the purpose of keeping count of the number of exposures made. By adjusting the knob of the relay, the unit may be preset to take a given number of pictures and then turn itself off. A maximum of 40 photographs can be taken with one loading of film. This number may be increased by changing the film loading cartridge and the step relay.

The shutter is of the focal plane type. It is kept in position against spring tension by a small movable latch placed

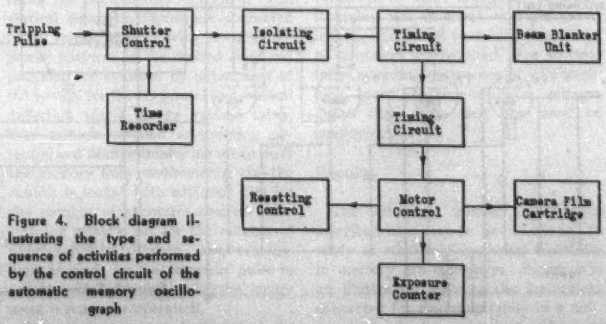


Figure 4. Block diagram illustrating the type and sequence of activities performed by the control circuit of the automatic memory oscillograph

close to the poles of an electromagnet. Release of the shutter is accomplished by exciting the current coil of the magnet.

The camera uses 35-millimeter film. Loading is accomplished by means of standard film cartridges. For photographing the green P1 medium-persistence screen, panchromatic-xx film gives excellent results. The lens has an opening of f1.5 and a focal length of three inches.

Control Circuit

Figure 4 is a block diagram illustrating the sequence of functions performed by the automatic memory oscillograph control circuit. The control is initiated by a voltage pulse applied to the grid of an electron tube. This pulse may be supplied by the transient voltage itself—or some other voltage pulse which occurs simultaneously with the transient to

Figure 7. Photographic record of oscillogram obtained with the automatic memory oscillograph connected as in Figure 6

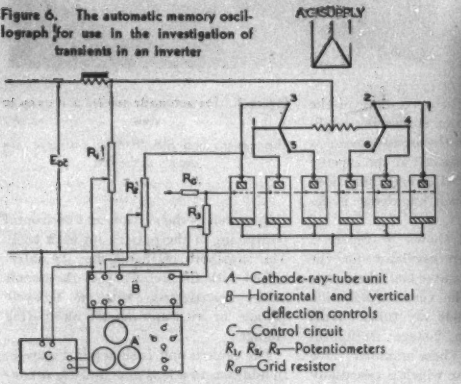
The camera shutter coil received its impulse at *A*. The cathode ray beam was blanked at *B*. The time at which the transient occurred is given by the clock *C*. Memory time preset at 50 milliseconds

e_{a-c}—Anode to cathode voltage for one anode of the inverter

e_{g-c}—Main direct voltage of the inverter

e_{g-c}—Grid to cathode voltage

Figure 6. The automatic memory oscillograph for use in the investigation of transients in an inverter



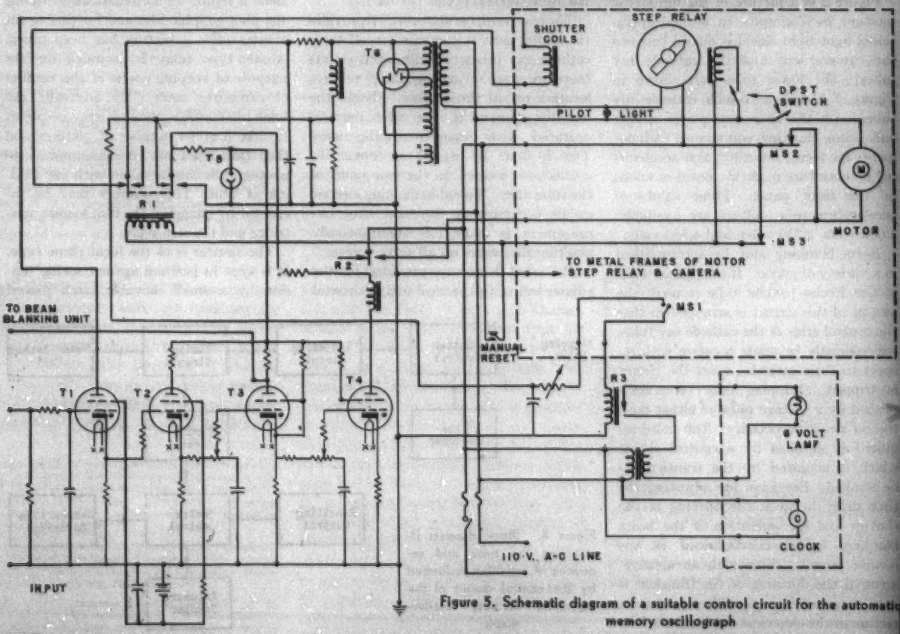


Figure 5. Schematic diagram of a suitable control circuit for the automatic memory oscillograph

Figure 8. Record of an oscillogram obtained with the automatic memory oscillograph when the anode being monitored suffers preignition

The ability of the oscillograph to record electrical conditions preceding, during, and after the occurrence of a transient is clearly indicated. Memory time preset at 50 milliseconds

Figure 9. Photographic record of an oscillogram illustrating a backfire followed by an arc-through on a polyphase mercury arc rectifier

Memory time approximately 50 milliseconds

be studied. As the input impedance of the control circuit is quite high, very little current is required for its operation.

The first operation is a multiple one. The shutter is opened, a clock dial is momentarily illuminated, and an electric pulse is released to an isolating circuit. An adjustable time thereafter the beam blanking unit receives its impulse, and a second timing circuit is actuated. The latter operates the motor control unit which in turn resets the camera, excites the coil of the step-relay exposure counter, and places the entire control circuit in readiness for the next transient to be recorded. The timing circuits are included in order to allow the adjustment of both memory time and exposure time. The clock mechanism insures that every oscillogram record contains the time at which the initiating transient occurred.

Figure 5 is a schematic diagram of a control unit, which may be used successfully to perform the sequence of operations illustrated in the block diagram of Figure 4. *T*1, *T*2, *T*3, and *T*4 are gas-filled control tubes. *T*6 is a rectifier tube for the power supply of the unit, and *T*5 is a voltage regulator tube. *MS*1, *MS*2, and *MS*3 are microswitches.

When the circuit is ready for operation, the relay contacts, *R*1, *R*2, and *R*3 are in the positions shown and tubes *T*1, *T*2, *T*3, and *T*4 are in a nonconducting state. Tube *T*1 controls the opening of the camera shutter and applies a positive voltage pulse to the grid of *T*2 which serves as an isolating tube. A variable resistor determines the time interval between the firing of tubes *T*2 and *T*3. The voltage pulse for operating the beam blanking circuit[4] is taken from the plate of *T*3. Tube *T*4 which will become conducting an adjustable time after *T*3 is fired, controls the operation of the motor that resets the camera and places the entire control circuit in readiness for the next transient pulse. The amount of motor travel is determined by two microswitches *MS*2 and *MS*3 operated by a cam on the motor shaft. An additional microswitch *MS*1 is actuated by the shutter when it reaches the bottom of its travel. Operation of *MS*1 causes the momentary illumination of a synchronous clock mechanism located in the light-tight shield placed between the oscillograph unit and the camera.

A bell may be placed across the terminals of the motor to attract attention when a transient is recorded.

Performance of the Unit

During operation, the cathode ray tubes are continuously energized. The vertical deflection inputs are connected to the voltage sources being investigated. Screen patterns of the desired sizes and positions are obtained by adjustment of the control for the horizontal and vertical deflection plates of the various tubes. The cathode-ray-tube accelerating potential and beam intensity are set to meet the memory time requirements, and the camera is loaded with sufficient film for the number of exposures desired. The stepping relay is set for the number of photographs to be taken. After arrangement is made for the transient pulse to operate the control circuit, the equipment is ready for operation.

Upon the occurrence of a transient, the camera shutter, normally closed, immediately is triggered open and the clock dial in the light shield is illuminated momentarily. Depending upon a preset delay time, the cathode ray beams are then extinguished. The fluorescent material on the cathode ray tubes retains the images on the cathode ray screens for a time sufficiently long so that successful photographic recording is accomplished. After a fixed delay the camera motor operates, closing the shutter, winding the film to the next frame, and resetting the control circuit. This places the memory oscillograph in readiness to record the next transient disturbance.

The accuracy of reproduction and the excellent frequency response of the oscillograph amplifiers make this cathode ray instrument suitable for the study of switching transients and other disturbances of short duration. In many instances the transient voltages being investigated are of such magnitude that no amplifiers are required. For successfully recording transients of extremely high speed, cathode-ray-tube voltages higher than those used here must be employed.[5]

Results

The automatic memory oscillograph described here may be put to use in the study of randomly occurring transients in mercury arc converters. Figure 6 is an illustration showing the instrument connected for recording faults in a mercury arc polyphase converter. The con-

Design and Measurements of Capacitor Discharge Welding Transformers

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Synopsis: A method is presented to calculate the size of core and windings of a capacitor discharge welding transformer required to supply a given welding current. It is further shown how the resistance and inductance of a certain welder can be determined from oscillograms of the current and voltage. The mathematical derivation of the formulas used is included.

FOR THE SPOT WELDING processes, where high instantaneous or closely controlled welding currents are required, an energy storage system will be of advantage. For this purpose, the capacitor discharge system has been developed. One typical application for this type of welding is the light metals, like aluminum and magnesium alloys, which require a high instantaneous and also closely controlled welding current. Another example is found in stainless steel whose welding current has to be of very short duration if carbide precipitation is to be avoided.

A capacitor discharge welder fundamentally consists of a series *RLC* circuit, with the energy originally stored in the capacitor and then discharged through the *RL* portion of the circuit by means of some switching device.

The resistance and inductance of a typical aluminum welder are in the order of 50 microhms and 1 microhenry respectively. To quote a specific weld schedule for 0.102-inch 24 ST "alclad" aluminum, this impedance must be matched with 2,520 microfarads to give peak current 0.029 second after the start of the current wave. It is the function of the welding transformer to effect this impedance match.

A classical analysis of the circuit which has been worked out and expanded for the oscillating condition is included in the appendix.

Let us first study the design of the transformer. For this purpose we investigate a welder which has been built to make a given weld. The resistance and inductance of this welder can be obtained from 60-cycle measurements. The inductance so obtained will remain relatively constant over a wide variation of current wave lengths, so this value can be used without appreciable error, but the resistance may vary by 100 per cent or more due to skin effect as the wave length deviates from one-half of a 60-cycle wave. The curves in Figure 1 show the ratio of 60-cycle resistance to actual resistance under capacitor discharge conditions for various wave lengths of a standard "Hi-Wave" welder.

For determining the size of a transformer core of a new welder, the desired time T_m to the first peak current, the value I_{2m} of the first secondary peak current necessary to do the welding job in question must be known from previous welding experience, for they are the fundamental requirements to which the welder shall be designed.

Then, as shown in the appendix,

$$\phi_T = \frac{1}{N_2} I_{2m} L_2 \times 10^8 \lambda(\tau_0) \qquad (35)$$

Paper 46-41, recommended by the AIEE committee on electric welding for presentation at the AIEE winter convention, New York, N. Y., January 21-25, 1946. Manuscript submitted October 5, 1945; made available for printing December 7, 1945.

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trol impulse is taken from a potentiometer placed across the direct voltage. Faulty anode firing will cause changes in the direct voltage and these changes initiate the operation of the oscillograph.

Simultaneous oscillograms of the main direct potential $e_{a\text{-}c}$, the anode to cathode voltage $e_{a\text{-}c}$ and the grid to cathode voltage $e_{g\text{-}c}$ are obtained with a circuit similar to that shown in Figure 6. Figure 7 is an illustration of a photographic record of faults occurring in an inverter. The memory time for this oscillogram has a preset value of about 50 milliseconds. The reproduction does not show all of the "memory" present in the original film. The camera shutter coil received its impulse at *A*, and cathode ray beam blanking occurred at *B*. Time proceeds from left to right.

The anode to cathode potential in Figure 7 shows that the disturbance recorded is due to the preignition of one of the inverter anodes. The regularity of the grid to cathode voltage indicates that the grid of the specific anode under observation suffers no ill effect due to this transient. A study of the wave shapes shown reveals the phase in which the fault occurs and the moment of initiation. The time at which the oscillogram is taken is shown by the counter dial *C* in the figure.

Figure 8 is an example of loss of grid control on the anode being monitored, and Figure 9 is an illustration of a case in which a "backfire" and a subsequent "shoot-through" occur.

Concluding Remarks

The automatic memory oscillograph can serve successfully in studying transients of a random character. Oscillograms may be obtained which are of value in the investigation of faults in the operation of apparatus such as mercury arc converters. It is possible to obtain information concerning the type of fault, the moment of its occurrence, its duration, and its severity. These data are of value in stimulating research and development work on all types of electrical equipment. As a laboratory tool, the automatic memory oscillograph may far surpass the ordinary oscillograph in utility. Its application to the study of physical phenomena in all branches of engineering where random transients must be investigated is only a matter of time. The study of mechanical transients by converting them into electric pulses suggests itself. The advantages possessed by virtue of the fact that the operation of this oscillograph is completely automatic, are obvious.

References

1. A New High-Speed Cathode-Ray Oscillograph, H. P. Kuehni, S. Ramo. AIEE Transactions, volume 56, 1937, June section, pages 721-8.

2. A Memory Attachment for Oscilloscopes, W. E. Pakala. AIEE Transactions, volume 57, 1938, December section, pages 682-4.

3. Photographic Patterns on Cathode Ray Tubes, Rudolph Feldt. *Electronics*, volume 17, February, 1944, pages 130-7.

4. A Beam Blanking Circuit for Oscilloscopes, Walther Richter. *Electronics*, volume 17, September, 1944, pages 128-30.

5. Theory and Operation of Electron Tubes (book), H. J. Reich. McGraw-Hill Book Company, New York, N. Y., page 206.

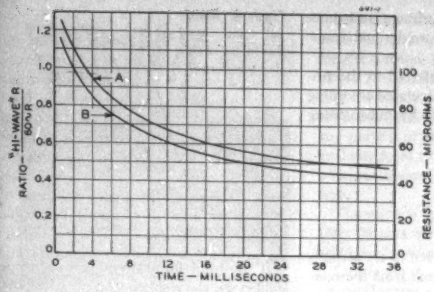


Figure 1. Variation of welder resistance as a function of wave shape

A—Ratio of actual resistance under capacitor discharge welding conditions, to 60~ resistance, as a function of time to peak current

B—Total welder resistance referred to the secondary winding plotted against time to peak current

where

ϕ_T = maximum flux change
N_2 = secondary turns
R_2 = total resistance referred to secondary (ohms)
L_2 = total inductance referred to the secondary (henrys)
$\lambda(\tau_o)$ = a function of τ_o (see Figure 2)
$\tau_o = \frac{T_o R_2}{\pi 2L_2}$
T_o = time to zero current (seconds)

The desired wave to make a given weld usually is expressed in terms of maximum current, and time to maximum current T_m; but T_o is required to solve equation 35. Equation 28 shows the relationship of T_m and T_o, and can be solved for T_o in the following way

Determine

$$g(\tau_o) = \frac{R_2}{2L_2} T_m$$

Obtain τ_o from the curve $g(\tau_o)$ in Figure 2, and calculate $T_o = \frac{2L_2}{R_2} \pi \tau_o$

Having evaluated τ_o, the amount of $\lambda(\tau_o)$ can be taken from the curve in Figure 2. The size of flux ϕ_T so obtained will be the total flux change. The first weld will leave the core magnetized with a residual flux which will vary with the type of core construction and the type of transformer steel used, but, in any case, it will be high enough to require a core of very large cross section unless it is compensated for. There are three ways to take care of this condition.

1. An air gap in the core for small transformers.

2. A magnetic flux bias by means of a direct current between welds.

3. Alternate reversal of the direction of the discharge through the welding transformer.

The third method will allow a simple economical design and therefore will be described in detail.

The residual flux for standard Hi-Wave transformers, when worked to maximum permissible flux density, is 42,000* lines per square inch and the core, which is made of special transformer steel, may be magnetized to 111,000 lines per square inch without measurable difference between primary and secondary ampere turns of the load current. This gives a maximum permissible flux density change per weld of 42,000 + 111,000 lines per square inch so that the net core area is total flux, as calculated by equation 35, divided by 153,000. Heating due to core loss need not be considered as even the highest welding speed possible at present would amount to only a very few cycles per second.

As can be seen from the problems just discussed, the accurate design of the core of a capacitor discharge welding transformer requires considerable experience, and measurements of similar setups, since most of the quantities which must be considered as known, vary with changing conditions of design, wave shape, and method of manufacture.

The next point for consideration is the copper.

Determination of effective current for the general circuit, that is for all combinations of L, R, and C, from the overdamped wave to a violently oscillating wave, is rather cumbersome from a mathematical approach.

A very large percentage of the total energy stored in the capacitor is lost in the welder and transformer so that we may assume, for design purposes, that the circuit must dissipate the total stored energy which may be expressed as

$$J = \tfrac{1}{2} CE^2$$

joules per weld where

$$C = L_2 \left[\frac{I_{2a}}{E} h(\tau_o)\right]^2 10^6 \text{ microfarad} \qquad (29)$$

C represents the capacity of the capacitor (microfarad). $h(\tau_o)$ can be taken from the curves in Figure 2.

The rate of energy dissipation or power will become

$$P = \tfrac{1}{2} CE^2 \frac{S}{60} \qquad (1)$$

Where J = energy in joules and S = average welding speed in spots per minute.

The power dissipated in the transformer will bear the same relation to the total power as its resistance referred to the secondary winding will bear to the total circuit resistance. It remains only to pick a desired efficiency η and, with welder resistance R_w known, to determine the corresponding total transformer resistance R_t referred to the secondary winding by the relationship $R_t = R_w \left(\frac{1}{\eta} - 1\right)$. With the resistance R_t determined, the copper sections can be calculated.

We now have iron cross section and copper cross section which furnish the physical size of the welding transformer. Having the loss and physical size, the temperature rise can be determined ac-

* The method of determining the residual flux will be presented later in this article.

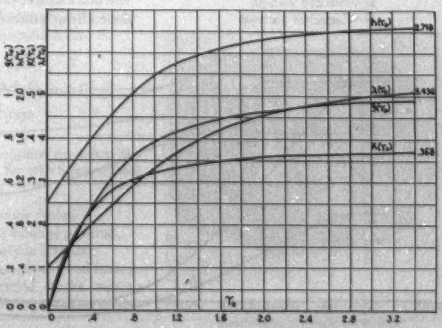


Figure 2. Characteristic functions of a capacitor discharge welding circuit

cording to standard transformer design practice which is outside the scope of this paper. The temperature rise may dictate water cooling which can be applied to the usually one turn secondary winding (see Figures 5 and 6), or it may require an increased copper section, or both.

The turns ratio remains to be fixed, and may be calculated from the expression

$$\frac{N_1}{N_2} = \frac{2Ek(\tau_o)}{I_{1a}R_2} \tag{30}$$

$K(\tau_o)$ can be taken from curves in Figure 2.

Measurements

The accuracy of a design, such as we just have considered, will depend largely on the experience of the designer and can be relied upon only when a suitable safety factor is applied which would be the correct procedure for one-of-a-kind design. When the design is to be used for a standard-line, a pilot unit should be built and accurate measurements made in order that some of the original assumptions may become definitely known quantities.

As has been stated before, all the characteristics which are considered more or less constant in the average electric circuit vary as the turns ratio and capacity are varied. It is, therefore, necessary to make measurements under the desired conditions, or over a range of capacity and turns ratio so that curves can be drawn.

Oscillograms are to be made of the primary current, of the capacitor voltage, and of a timing wave, usually 1,000 cycles. (See Figure 3.) From this we can measure all characteristics of the wave necessary for determining primary resistance and inductance of the welder and transformer circuit.

The inductance L_1 referred to the primary winding can be calculated according to equations 27 to 30, by substituting valves for g, h, and k, as

$$L_1 = \frac{T_o^2 \tan^2 \pi \frac{T_m}{T_o}}{\pi^2 C\left(1+\tan^2 \pi \frac{T_m}{T_o}\right)}$$

The inductance L_2 referred to the secondary winding may be found from the relationship

$$L_2 = \frac{L_1}{a^2}$$

where a = turns ratio.

The next step is the determination of the resistance of the circuit. From equation 31 we find

$$\frac{I_{1b}}{I_{1a}} = \epsilon^{-\pi\tau_o} \tag{31}$$

Where I_{1a} and I_{1b} are peak values of the primary current for the first and second half cycles respectively of the oscillating wave.

From equation 31 we find

$$\tau_o = \frac{T_o}{\pi}\frac{R_1}{2L_1} = \frac{1}{\pi}\log_\epsilon \frac{I_{1a}}{I_{1b}}$$

and determine

$$R_1 = \frac{4.61L_1}{T_o}\log_{10}\frac{I_{1a}}{I_{1b}} \tag{2}$$

Having obtained actual values of R, L, T_m, T_o, and I, it is possible to make a more accurate determination of total flux change, equation 35. In addition to this we will have to find the magnitude of the actual core flux. Furthermore, the entire mathematical analysis presupposes that applied voltage is equal to induced voltage, which is not strictly true, due to IR and IX drops in the transformer primary winding. The flux change, therefore, must be determined from induced voltage oscillograms.

Figure 3. Oscillogram taken in the primary circuit of a capacitor discharge welder

A—Magnetizing watts
B—Magnetizing current
C—Primary current
D—Induced voltage
E—Capacitor voltage

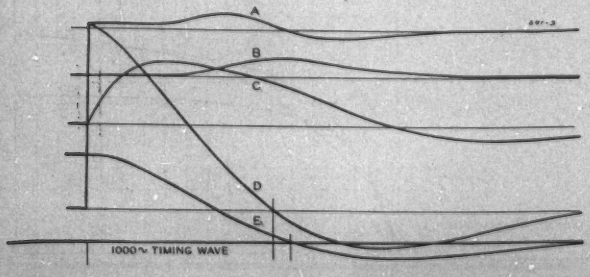
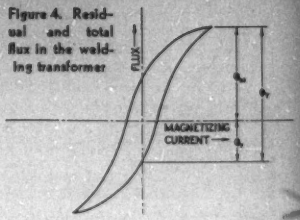


Figure 4. Residual and total flux in the welding transformer



If the total flux change to produce a weld is ϕ_T, the residual flux is ϕ_r, and the maximum flux to which the iron actually is magnetized is ϕ_m (see Figure 4) then we may write

$$\phi_T = \phi_r + \phi_m \tag{3}$$

The unsymmetry of the hysteresis loop describing the reversal of the flux shall be neglected. Since we can test directly only ϕ_T, we must find a method to determine one of the other two quantities, ϕ_r or ϕ_m, in order to apply equation 3.

It was decided to measure the flux ϕ_m. As there are no pole manifestations on a transformer core, this could be done only by comparing the magnetizing current of a typical transformer with a d-c magnetization curve of the same transformer which had been prepared from 60-cycle oscillograms. To obtain the magnetizing current, it was necessary to connect the transformer primary winding in parallel with another identical transformer which had been installed in a welding machine in the normal manner. Both transformers had the same residual ϕ_r. The voltage wave form of the transformer under test was identical with that of the transformer which actually was welding, and as the test transformer's secondary winding was open, its primary winding carried only magnetizing current. After several previous discharges with the same energy, an oscillogram of the magnetizing current was taken, and its peak value was compared with the d-c magnetization curve to determine the flux ϕ_m. This value of ϕ_m is subject to the same error as that caused by considering capacitor voltage to be the same as transformer induced voltage, because the primary winding of the test transformer carries only magnetizing current, and hence the difference between induced voltage and applied voltage will be negligible. This means that the test transformer's induced voltage will be equal to the welding transformer's applied voltage. A correction factor for any one setting of capacity, voltage, and turns ratio can be established. If the total flux change is calcu-

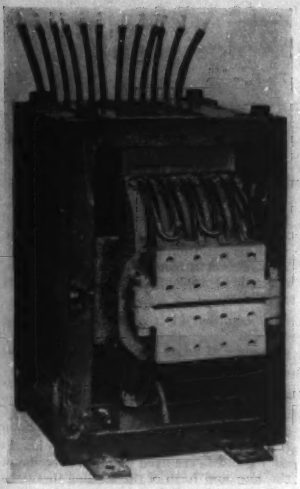


Figure 5. Standard "Hi-Wave" welding transformer

lated on the basis of capacitor voltage and called ϕ_{TC} and again is calculated on the basis of induced voltage and called ϕ_{TE}, then the actual flux to which the iron is excited may be stated as

$$\phi_m = \frac{\phi_{TE}}{\phi_{TC}} \phi_m \text{ (test)} \qquad (4)$$

if we assume the ratio of the corresponding residual fluxes ϕ_r is the same as that of the main fluxes ϕ_m and ϕ_m (test). It now remains to determine the total flux change accurately.

The fundamental voltage equation is

$$e = N\frac{d\phi}{dt} \times 10^{-8} \qquad (5)$$

where

N = number of turns
e = instantaneous voltage

From this we can write

$$\phi = \frac{10^8}{N}\int_{t_1}^{t_2} e\,dt \qquad (6)$$

where t_1 represents the time at the beginning of discharge and t_2 any time thereafter. Then $\int_{t_1}^{t_2} e\,dt$ represents the area under the voltage curve which equals

$$te \text{ (average)} \qquad (7)$$

so that we may write total flux change

$$\phi_T = \frac{10^8 t}{N} e \text{ (average)} \qquad (8)$$

Inspection shows that this expression holds completely only for an oscillating condition where T_0 is finite, since in a case where T_0 is infinite, e will approach o and the expression becomes indeterminate. Equation 8 can be evaluated, however, for any portion of the wave so that we may evaluate from $t = o$ to a value of t where e (instantaneous) is practically equal to zero.

The value te (average) may be obtained from the area under the oscillogram of the voltage e by some graphical method.

In this way ϕ_{TC} can be determined from an oscillogram of the capacitor voltage. An induced voltage oscillogram will give the actual total flux change ϕ_{TE}.

The induced voltage can be measured by placing a search coil of several turns evenly distributed on the center core leg next to the iron.

To summarize:

1. Total flux change ϕ_{TE} can be determined by applying equation 8 to an induced voltage wave.

2. Maximum flux to which the core is excited is according to equations 4 and 8.

$$\phi_m = \frac{te \text{ (average) from induced voltage}}{te \text{ (average) from capacitor voltage}} \times \phi_m \text{ (test)} \qquad (9)$$

where ϕ_m (test) is read from a magnetization curve of the transformer in question, having measured its magnetizing current as described previously.

This method of determining maximum flux and flux change was developed to measure accurately the flux conditions of a previously designed line of transformers with a view of possible refinement of the design. Its usefulness lies in the fact that any piece of equipment whose induced voltage can be recorded on an oscillogram may be investigated, regardless of the complexity of the induced voltage wave.

Pictures of the assembly and of the secondary winding of a standard Hi-Wave CC1T capacitor discharge welding transformer are shown in Figures 5 and 6.

Appendix. Mathematical Analysis

Figure 7 shows a simplified capacitor discharge welding circuit for which we will use the following symbols:

e = voltage across capacitor (volts)
E = maximum or initial value of e (volts)
C = capacitance of capacitor (farads)
R_1; L_1 = total resistance (ohms) and leakage inductance (henrys) of the welding transformer referred to the secondary side
R_w; L_w = total resistance (ohms) and inductance (henrys) of the external secondary welding circuit
R_C; L_C = total resistance (ohms) and inductance (henrys) of the external primary capacitor circuit
R_1; L_1 = resultant resistance (ohms) and inductance (henrys) referred to the primary side
R_2; L_2 = resultant resistance (ohms) and inductance (henrys) referred to the secondary side
N_1; N_2 = primary and secondary number of turns
$a = \frac{N_1}{N_2}$ = turns ratio
i_1; i_2 = primary and secondary currents (amperes)
I_1; I_2 = maximum values of i_1 and i_2 (amperes)
I_{1a}; I_{1b}; I_{2a}; I_{2b} = first and second maximum values of i_1 and i_2 for oscillating discharge (amperes)
kva$_C$ = power rating of capacitor referred to 60-cycle excitation (kilovolt-amperes)
ϕ_T = maximum flux change of magnetic core flux of welding transformer (maxwells)
T = time (seconds) to any current peak $i_1 = I_1$ or $i_2 = I_2$
T_m = time (seconds) to first current peak
T_0 = time (seconds) of half cycle of i_1 and i_2
T_C = time (seconds) to first zero e
n = number of current peaks up to time T

[Since R_c and L_c of the capacitor circuit may be neglected, we may write $R_2 = R_1 + R_w$; $L_2 = L_1 + L_w$]

The general circuit equations are

$$L_1\frac{d^2i_1}{dt^2} + R_1\frac{di_1}{dt} + \frac{i_1}{C} = 0$$

$$i_1 = -C\frac{de}{dt}$$

Introducing

$$Z = \sqrt{\left(\frac{R_1}{2}\right)^2 - \frac{L_1}{C}} \qquad (10)$$

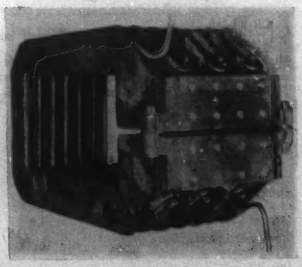


Figure 6. Standard "Hi-Wave" welding transformer secondary winding

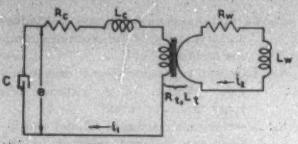


Figure 7. Simplified capacitor discharge welding circuit

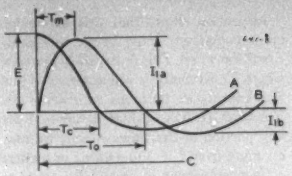


Figure 8. System of current and voltage oscillations of the primary capacitor circuit

A—Capacitor voltage *e*
B—Primary current i_1
C—Time *t*

The complete solution is

$$i_1 = A\epsilon^{-\frac{1}{L_1}\left(\frac{R_1}{2}-x\right)t} + B\epsilon^{-\frac{1}{L_1}\left(\frac{R_1}{2}+x\right)t}$$

$$e = A\left(\frac{L_1}{C}\right)\left(\frac{\epsilon^{-\frac{1}{L_1}\left(\frac{R_1}{2}-x\right)t}}{\frac{R_1}{2}-Z}\right) + B\left(\frac{L_1}{c}\right)\times\left(\frac{\epsilon^{-\frac{1}{L_1}\left(\frac{R_1}{2}+x\right)t}}{\frac{R_1}{2}+Z}\right)$$

where A and B are constants of integration. A and B are determined from the boundary conditions $t=0$; $i=0$; $e=E$ so that we obtain

$$i_1 = \frac{E}{Z}\epsilon^{-\frac{R_1}{2L_1}t}\sinh\frac{Z}{L_1}t \tag{11}$$

$$e = E\epsilon^{-\frac{R_1}{2L_1}t}\left[\frac{R_1}{2Z}\sinh\frac{Z}{L_1}t + \cosh\frac{Z}{L_1}t\right] \tag{12}$$

to get the maximum value I_1 of i_1 determine $\frac{di_1}{dt}$ from equation 11, equate to zero, solve for i_1, introduce $i_2 = ai_1$; $a^2R_2 = R_1$; $a^2L_2 = L_1$, and obtain

$$T = \frac{L_1}{Z}\tanh^{-1}\frac{2Z}{R_1} \tag{13}$$

$$I_1 = E\sqrt{\frac{C}{L_1}}\epsilon^{-\frac{R_1}{2L_1}T};\quad I_2 = E\sqrt{\frac{C}{L_2}}\epsilon^{-\frac{R_2}{2L_2}T} \tag{14}$$

The foregoing solutions are general. For a numerical application the following three special cases should be considered.

Case 1. Aperiodic Discharge

$\left(\frac{R_1}{2}\right)^2 > \frac{L_1}{C}$; Z of equation 10 is real so that we may apply equations 10 to 14 directly. Since there is only one maximum $I_1 = I_{1a}$ or $I_2 = I_{2a}$ of the currents i_1 and i_2, we may write $T = T_m$ and obtain for

$$\text{kva}_C = \frac{1}{2}(2\pi 60)\frac{CE^2}{1{,}000}$$

the expression

$$\text{kva}_C = 0.1885 I_{2a}^2 L_2 \epsilon^{\frac{R_2}{L_2}T_m} \tag{15}$$

or

$$\text{kva}_C > 1.4 I_{2a}^2 L_2$$

Case 2. Periodic Discharge

$\left(\frac{R_1}{2}\right)^2 < \frac{L_1}{C}$; Z of equation 10 is imaginary so that we transform

$$\sqrt{\left(\frac{R_1}{2}\right)^2 - \frac{L_1}{C}} = j\sqrt{\frac{L_1}{C} - \left(\frac{R_1}{2}\right)^2}.$$

By using a real

$$Z = \sqrt{\frac{L_1}{C} - \left(\frac{R_1}{2}\right)^2} \tag{16}$$

we may write instead of equations 11 to 14

$$i_1 = \frac{E\epsilon^{-\frac{R_1}{2L_1}t}}{Z}\sin\frac{Z}{L_1}t \tag{17}$$

$$e = E\epsilon^{-\frac{R_1}{2L_1}t}\left[\frac{R_1}{2Z}\sin\frac{Z}{L_1}t + \cos\frac{Z}{L_1}t\right] \tag{18}$$

$$T_m = \frac{L_1}{Z}\tan^{-1}\frac{2Z}{R_1};\quad T = T_m + (n-1)\pi\frac{L_1}{Z} \tag{19}$$

The expressions for I_1 and I_2 remain the same as in equation 14 while I_{1a} and I_{2a} are represented by

$$I_{1a} = E\sqrt{\frac{C}{L_1}}\epsilon^{-\frac{R_1}{2L_1}T_m};\quad I_{2a} = E\sqrt{\frac{C}{L}}\epsilon^{-\frac{R_2}{2L_2}T_m} \tag{20}$$

Kva_C is given by equation 15 and lies between the limits

$$0.1885 I_{2a}^2 L_2 < \text{kva}_C < 1.4 I_{2a}^2 L_2.$$

Case 3. Limit of Aperiodic Discharge

$\left(\frac{R_1}{2}\right)^2 = \frac{L_1}{C}$; Z becomes zero. In substituting $Z=0$ in equations 17 to 19 we have to evaluate the expressions

$$\lim_{Z\to 0}\left(\frac{\sin\frac{Z}{L_1}t}{Z}\right) = \frac{t}{L_1};\quad \lim_{Z\to 0}\left(\frac{\tan^{-1}\frac{2Z}{R_1}}{Z/L_1}\right) = \frac{2L_1}{R_1}$$

and obtain, instead of equations 15 and 17 to 19

$$i_1 = \frac{E}{L_1}t\epsilon^{-\frac{R_1}{2L_1}t} \tag{21}$$

$$e = E\left(\frac{R_1}{2L_1}t + 1\right)\epsilon^{-\frac{R_1}{2L_1}t} \tag{22}$$

$$T = T_m = \frac{2L_1}{R_1} \tag{23}$$

$$I_2 = 0.368\sqrt{\frac{C}{L_2}}E \tag{24}$$

$$\text{kva}_C = 1.4 I_{2a}^2 L_2 \tag{25}$$

In spite of the fact that equations 11, 17, and 21, for example, are of greatly different form, it can be seen from the reasoning in developing equation 21 from 17, and a similar process could be applied to develop equation 21 from equation 11, that for $\left(\frac{R_1}{2}\right)^2 \leqslant \frac{L_1}{C}$ the equations 21 to 25 could be used, without great error for either case 1 or 2.

For the purpose of machine design, equations 15 to 20 for the periodic discharge case 2 shall be transformed so that the desired machine constants may be determined for any specific wave form. In this analysis R_2 and L_2 are fixed with the selection of the size and form of the welding throat as well as of the efficiency and per cent impedance of the welding transformer. I_2 and T_m are determined by the desired welding effect, and E may be fixed if we standardize on a certain value of capacitor voltage.

If instead of T_m the time T_o of the first half current cycle is introduced, it will be possible to determine explicitly, all other values, like $a = \frac{N_1}{N_2}$; I_{1a}; E; ϕ_T; L_1 and R_1 as functions of the given circuit constants. T_o is obtained from equation 17 for $i = o$ by

$$\frac{Z}{L_1}T_o = \pi$$

or

$$T_o = \frac{L_1\pi}{Z};\quad Z = \sqrt{\frac{L_1}{C} - \left(\frac{R_1}{2}\right)^2} \tag{26}$$

This value of T_o is introduced into equations 15 to 20 by combining the functions

$$\left.\begin{aligned} \tau_o &= \frac{T_o}{\pi}\frac{R_2}{2L_2} \\ g(\tau_o) &= \tau_o\tan^{-1}\frac{1}{\tau_o} \\ h(\tau_o) &= \epsilon^{g(\tau_o)} \\ k(\tau_o) &= \frac{\tau_o}{\sqrt{1+\tau_o^2}}\frac{1}{h(\tau_o)} \\ \lambda(\tau_o) &= \frac{\tau_o}{\sqrt{1+\tau_o^2}}h(\tau_o)\left[\frac{-\pi\tau_o}{k(\tau_o)}+2\right] \end{aligned}\right\} \tag{27}$$

$g(\tau_o)$; $h(\tau_o)$; $k(\tau_o)$; $\lambda(\tau_o)$ are plotted against τ_o in Figure 2. Using the values taken from these curves, we may write instead of equations 15 to 20

$$T_m = \frac{2L_2}{R_2}g(\tau_o);\quad T = T_m + (n-1)T_o;\quad T_C = T_o - T_m \tag{28}$$

Phonograph Reproducer Design

W. S. BACHMAN
NONMEMBER AIEE

PHONOGRAPH reproducers, which convert the mechanical motion of the stylus to a corresponding electric voltage, have been in commercial use for the past two decades. They have employed a wide variety of voltage generators such as carbon microphone buttons, variable reluctance magnetic circuits, moving coils in magnetic fields, and Rochelle salt crystals. Although excellent performance has been obtained with many of these types, there has been a continued effort to reduce the mass of the moving system and to simplify the mechanical construction, even to the extent of sacrificing output voltage.

While the carbon button type of reproducer was one of the first to appear, it was soon outmoded by subsequent types. The variable resistance principle, however, again is employed in one of the reproducers to be described in this paper. An important difference between it and the carbon button type is that the variable resistance element is a fine metallic wire the resistance of which changes in response to strain. These wires may be of the same material as is used in strain gauges, but in this case there is no need to determine the absolute value of the strain, since only the voltage resulting from the change in strain is utilized. This imposes the requirement of linearity, if distortion is to be avoided, which easily is met by most of the commonly used strain sensitive wires. Measurements have shown that the ratio of change of resistance to change of length is constant through and even beyond the elastic limit of the wire.[1]

One of the first successful designs employing a wire resistance strain element is shown in Figure 1. The stylus is carried in a small cantilever beam 9, and the strain element 14 is attached to it at a point about 1/3 of its length from the fixed end. The strain wire is held in tension sufficient to stress it about halfway to its elastic limit by the piano wire springs 15, and the Textolite pins 16 serve as snubbers to prevent the tension springs from following the motion of the cantilever. The circuit employed to polarize this reproducer is shown in Figure 2.

Since the voltage derived from the strain is proportional to the displacement, the output of this reproducer is proportional to the displacement of the stylus by the record. This makes it easy to check the frequency characteristic without knowing the actual displacements which are pressed on a frequency, or constant tone record. If the same band is driven at various speeds, the amplitude of the reproduced wave should be the same. This was found to be true from 10,000 cycles down to the low frequency resonance except for a wave form distortion at about 6,500 cycles, which was found later to be caused by the second mode of vibration of the cantilever which occurred at 13,000 cycles. This could be damped readily by placing a small block of a material such as Pyralin approximately at the loop of the second mode of vibration, at which point a negligible amount of loading would be reflected to the stylus tip for the fundamental mode of vibration. These modes of vibration are shown in Figure 3.

Although the output voltage was low, about −65 decibels below 6 milliwatts with a displacement of 0.0003 inch (Columbia WT-1, frequency record, 1,000 cycle band), the performance was very nearly ideal. In order to avoid variations in tension the design shown in Figure 4 was evolved. The strain wires were soldered to 1/16 inch diameter rods which were free to move axially in holes provided in the Textolite mounting block. The tension, as previously, was applied by means of piano wire springs, but instead of the snubbers the rods were lubricated with a viscous liquid which readily permitted them to move slowly in an axial direction to equalize variations in tension in the strain wire, but offered a high impedance to the motion resulting from the rapid strain variations due to the useful stimulation of the cantilever. In other words the strain wires were resistance terminated.

Another solution of the termination problem is shown in Figure 5. In this model use is made of the fact that an increase in strain on one side is accompanied by a decrease on the other. If both ends were terminated at the same point, the two forces would balance out. The tiny bell cranks 35 at the root of the cantilever serve to change the direction of the strain by approximately 90 degrees, and the ends of the strain element both are attached to the yoke 36, which applies the desired tension to them.

All of these designs require the use of the strain elements under tension, restricting their operating range to about half of their potential range. In order to make use of the compression as well as the tension range, the design in Figure 6 was developed. Although not shown in the

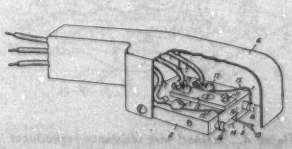


Figure 1. Early form of strained wire resistance reproducer

Paper 46-32, recommended by the AIEE committee on communication for presentation at the AIEE winter convention, New York, N. Y., January 21-25, 1946. Manuscript submitted November 19, 1945; made available for printing December 17, 1945.

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$$C = L_2\left[\frac{I_{2a}}{E}h(\tau_0)\right]^2 10^6 \text{ microhms} \quad (29)$$

or

$$E = \sqrt{\frac{L_2}{C}}\, I_{2a} h(\tau_0) 10^3$$

$$\frac{N_1}{N_2} = \frac{E}{I_{2a}} \frac{2k(\tau_0)}{R_2} \quad (30)$$

or

$$I_{2a} = \frac{N_2}{N_1} \frac{2k(\tau_0)}{R_2} E$$

$$\frac{I_{2b}}{I_{2a}} = \frac{I_{1b}}{I_{1a}} = -\epsilon^{-\pi\tau_0} \quad (31)$$

$$\frac{i_2}{I_{2a}} = \frac{\tau_0}{k(\tau_0)}\, \epsilon^{-\tau_0\pi\frac{t}{\tau_0}} \sin \pi \frac{t}{T_0} \quad (32)$$

$$\frac{e}{E} = \epsilon^{-\tau_0\pi\frac{t}{\tau_0}}\left[\tau_0 \sin \pi \frac{t}{T_0} + \cos \pi \frac{t}{T_0}\right] \quad (33)$$

$$\text{kva}_C = 0.1885 L_2 [I_{2a} h(\tau_0)]^2 \quad (34)$$

Calculate also

$$\phi_T = \int_0^{\tau_0} \frac{e 10^8}{N_1}\, dt$$

and obtain

$$\phi_T = \frac{1}{N_2} I_{2a} L_2 10^8 \lambda(\tau_0) \quad (35)$$

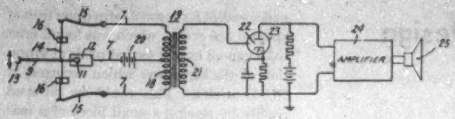


Figure 2. Circuit for polarizing variable resistance reproducer

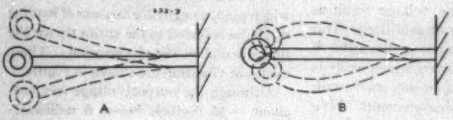


Figure 3
A—Normal mode of vibration of cantilever stylus support
B—Second mode of vibration

figure, the back end of the cantilever 55 is fastened to a stud which mounts rigidly to the tone arm. In it the strain wires were cemented to the cantilever itself to measure the strains in the outer fibers of the beam. Being attached in repose, they are subjected to both tension and compression. Although a strain element need be applied to only one side of the cantilever, it actually was applied to both, principally to permit balancing of the direct current in the primary winding of the input transformer. In this form the resistance reproducer lends itself readily to the application of a new technique for the damping of the resonance between the supporting arm mass and the suspension compliance.

It is usual, in most pickup designs to obtain damping of this resonance by introducing some dissipation in the pivots or bearings, such as by the use of rubber sleeves or blocks on the axis of oscillation. This imposes an additional load upon the record, as may be seen from a study of the electrical equivalent of the mechanical system, as shown in Figure 7.

Inspection of the equivalent electric circuit of such a reproducer, Figure 7B, shows that the presence of R is desirable to limit the impedance rise at the resonance frequency. In the useful audible range above the resonance the proper operation of the pickup depends upon the motion of M being negligible in response to signal stimulation. This requires that practically all of the applied motion be suffered by R and C (practically all of the current must travel through the path R, C). If R were omitted, the needle point impedance would decrease with frequency, but in the equivalent circuit it readily is seen that it can never drop below R as the frequency increases.

To give a quantitative illustration of the importance of this problem, consider a pickup and tone arm assembly having an effective arm mass (referred to the needle point) of 30 grams and a suspension compliance of 10^{-4} centimeter per dyne. For critical damping of the arm resonance it would require

$$R^2 = \frac{4M}{C} = \frac{4\times 30}{10^{-4}} = 120\times 10^4$$

$$R = 10.9\times 10^3 \frac{\text{dyne seconds}}{\text{centimeters}}$$

Under stimulation of 15 centimeters per second, a quite usual value of velocity, a lateral force of

$$F = RV = 10.9\times 10^3 \times 15 = 165\times 10^3 \text{ dynes or } 167 \text{ grams}$$

would be developed. Assuming 45-degree inclined groove walls, a bearing weight of 5.9 ounces would be necessary to keep the needle in contact with the groove.

Of course it is not necessary to provide critical damping of the tone arm resonance, but, if the damping is not sufficient, the reproducer will be very unstable when shock excited and even may tend to jump out of the grooves of a warped or uneven record. In many designs the bearing upon the record is made large for this reason alone.

Because of the extremely small size of the generator unit shown in Figure 6 and the fact that the output voltage is obtained as a result of the bending of the cantilever only, it became possible to apply a new arm resonance damping technique. The mechanical schematic of the system is shown in Figure 8A. The electrical equivalent of the system is shown in 8B. It is obvious in the circuit of 8B that the resonance may be damped critically without any increase in the mechanical impedance above resonance. Such a system is not mechanically stable, however, as is evident from inspection of Figure 8A. In this mechanical system there is no restoring force available to keep the needle point and the arm from wandering away from each other as energy is dissipated in R. In other words the resistor must be restricted from any except oscillatory motion. This is done by the system shown in 8C and 8D. If C_1 is made very large, the circuit of 8B approaches the performance of 8C, except that a new resonance, which would be damped only very lightly, appears at the frequency where the reactance of C_1 and C_2 in parallel is equal to the reactance of m. By proper choice of C_1 and C_2, R may be made effective for both resonance frequencies, as may be seen from the curve of mechanical impedance at the needle point versus frequency shown in Figure 9.

Figure 10 shows a design of the resistance pickup employing this new type of arm resonance damping. Corresponding to the element R in Figure 8 are the rubber sleeves bearings 72, and the Pyralin disc 74; all are in torsion. The compliance C_3 is that of the spring 80. This reproducer with only 15 grams of bearing weight on the record would not leave the groove even with quite violent shocks ap-

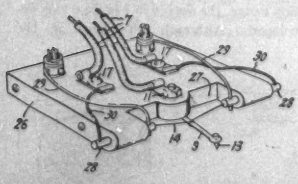


Figure 4. Strained wire resistance reproducer with means for maintaining uniform tension in resistance wire

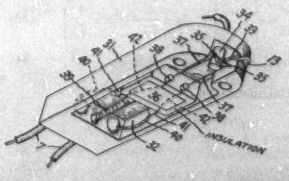


Figure 5. Alternate form of strained wire resistance reproducer in which opposing strains are balanced against each other

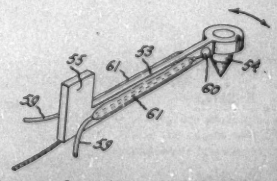


Figure 6. Strained wire resistance reproducer element having strain wires applied directly to the cantilever to measure strain in its outer fibers

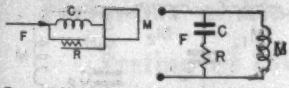


Figure 7A (above, left). Mechanical schematic diagram of a reproducer having damping material at its pivots

F = force exerted by needle upon record
C = compliance of suspension
R = mechanical resistance represented by the damping material
M = mass of cartridge and arm
Mass of needle is neglected being insignificant at low frequency

Figure 7B (above, right). Electrical equivalent of mechanical system shown in Figure 7A (motions of the mechanical elements are represented as currents in the electric network)

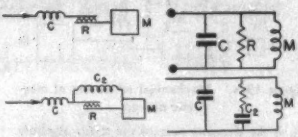


Figure 8A (above, upper left). Mechanical schematic diagram of a reproducer having a preferred form of low frequency resonance damping

Figure 8B (above, upper right). Electrical equivalent of system shown in Figure 8A

Figure 8C (above, lower left). Practical mechanical system retaining advantages of idealized system shown in Figure 8A

Figure 8D (above, lower right). Electrical equivalent of system shown in Figure 8C

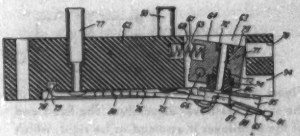


Figure 10. Design of strained wire resistance reproducer utilizing element of Figure 6 and having damping applied as shown schematically in Figure 8C

plied to the motor board and turntable. The effect of this damping system was observed by watching the displacement output of the reproducer on an oscilloscope while a tone band of a frequency record was allowed to coast down from rated speed to zero. The observed amplitude remained uniform until the resonant frequency, approximately 25 cycles, was nearly reached, below which the amplitude dropped smoothly. No rise before cutoff occurred.

While the strained wire resistance reproducer provides nearly ideal performance, the techniques acquired during its development are by no means limited to its type of generator element. The following is a description of a variable reluctance or magnetic type of reproducer embodying similar mechanical design considerations.

The fact that even a simple cantilever carrying the stylus at its free end required some damping to restrain its second mode of vibration, as mentioned in reference to Figure 3, made it very evident that no more complicated system could be relied upon to transmit the motion of the stylus tip to an armature or reed without introducing a frequency characteristic describing their relative motions. Accordingly a design was worked out in which the armature is right at the stylus, so that the motion of the armature is inseparably that of the stylus. Obviously this design could have no frequency characteristic as long as the stylus properly traces the groove, the output voltage being proportional to the stylus velocity.

The armature is a steel ribbon having a cross section of 0.010 inch by 0.030 inch. As may be seen from Figure 11, it has a 90 degree twist near the fixed end, which makes possible nearly as much compliance in the vertical direction as is provided laterally. This is desirable to permit the stylus to recede within the guard, provided by the two pole faces, when subjected to excessive downward forces such as in dropping. The small block of Pyralin just forward of the twist provides sufficient damping to restrain the second mode of vibration of the cantilever, which has already been discussed. At the free end the width of the armature is increased to receive the stylus. The dynamic mass of this stylus armature assembly is in the order of 8 milligrams. This mass is suspended on the spring, represented by the cantilever, the mechanical schematic of which is shown in Figure 12A. The electrical equivalent, Figure 12B, is a simple series circuit which expresses the mechanical impedance at the stylus tip. At low frequencies the system is stiffness controlled, and the impedance therefore decreases linearly with frequency until the resonance of M_1 and C is reached. The impedance at this resonance becomes very nearly zero, since very little mechanical resistance is reflected to the stylus tip from the Pyralin damping block attached near the fixed end of the cantilever. This, then, is the frequency at which practically no force is required to move the stylus, and with the values of

Figure 9. Low frequency needle point impedance and response of magnetic phonograph reproducer

⊙ Measured values

$\text{Response} = \frac{R_c}{Y}$

$C = 0.875 \times 10^{-6}$ centimeter per dyne
$C_2 = 3.54 \times 10^{-6}$ centimeters per dyne
$R = 6{,}000$ dyne seconds per centimeter

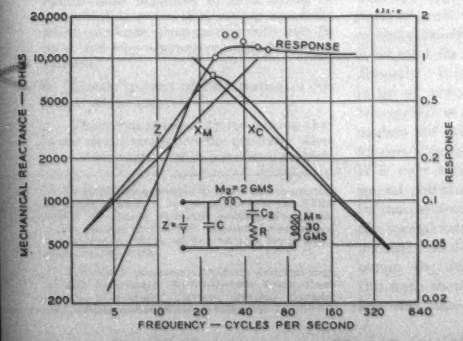
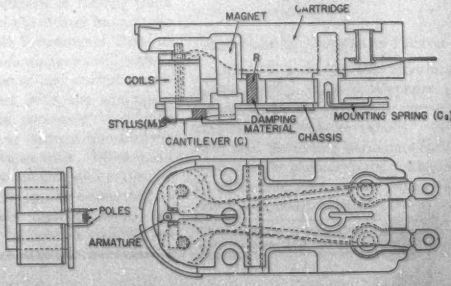


Figure 11. Magnetic or variable reluctance reproducer



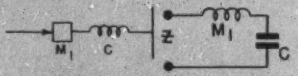


Figure 12A (left). Mechanical schematic of the stylus cantilever assembly. The fixed end of the cantilever is assumed to be rigid, which is very nearly so at high frequencies

M_1 is the dynamic mass of the stylus assembly
C is the compliance of the suspension

Figure 12B (above, right). Electrical equivalent of system shown in Figure 12A

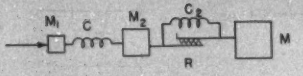


Figure 13A. Mechanical schematic of magnetic pickup

M_1 is the dynamic mass of the stylus assembly
C is the suspension compliance
M_2 is the mass of the coils, poles, and magnet assembly
R is the arm resonance damping
C_2 is the compliance which provides the operating point for R
M is the cartridge and arm mass

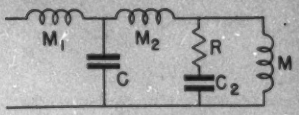


Figure 13B. Electrical equivalent of system of Figure 13A

dynamic mass and suspension compliance noted previously it occurs at approximately 2,300 cycles per second.

Above this resonance the system is mass controlled, the impedance rising linearly with frequency. Because the mass is so small, this system will remain in contact with both side walls of a 45 degree inclined side wall groove under acceleration of 2,000 g with a bearing weight upon the record of only 16 grams.

The mechanical system shown in Figure 12 accurately represents the needle point impedance except at the low frequency end of the range, where the dynamic mass of the arm and cartridge resonates with the compliance C. This condition was discussed with reference to Figure 8, and the same treatment for the control of this resonance is applied to this magnetic design. Again referring to Figure 11, the poles, coils, magnet, and armature all are mounted upon a chassis which is spring-mounted to the cartridge and arm assembly. Between the chassis and cartridge another block of Pyralin is inserted which provides the mechanical damping resistance, R. The mechanical system of the magnetic reproducer is shown in Figure 13A. It differs from that of Figure 8C in the presence of M_2. If this mass is too large, the resonance of M_2 with C and C_2 in series may be low enough so that R is not very effective, giving another frequency at which high impedance appears at the needle point. If M_2 is small enough to avoid this condition, it may be neglected. In this particular design the total weight of the magnet, coil, poles, and chassis assembly is approximately two grams. Figure 9 shows the calculated mechanical impedance, Z, of the magnetic reproducer, taking M_2 into account. The two asymptotes which the curve approaches correspond to the reactances of the suspension compliance C, and the total mass, M_1 and M. It is seen that the resonant rise is very slight.

The frequency response characteristic of this reproducer may be calculated by finding the ratio of the admittance of the path through C, referring to Figure 9, to the total admittance of the circuit. This is the same as the ratio of the motion of the cantilever to the motion imparted to the stylus tip, the open circuit voltage output of the reproducer being proportional to the velocity of motion of the cantilever. The network may be considered to be fed from a constant current source, the record groove being a stiff or high impedance source.

Also plotted in Figure 9 are measured values of response which were obtained by first measuring the output of the cartridge supported in an arm, and repeating the run with the cartridge clamped in a vise, the ratio of these values indicating the low frequency response. The source for these measurements was a crystal cutter head the exact mechanical impedance of which was not determined but which, because of the head's very evident stiffness, was regarded to be high. The agreement with the calculated response is reasonable considering this and also that the damping material is not a pure mechanical resistance. Similar technique was employed as mentioned previously in the case of the resistance pick-up for determining the response in the range above arm resonance, with the important difference that the electric output was integrated before being fed to an oscilloscope. Under these conditions no change in amplitude of the trace was observed, regardless of the rotational speed, below 78 rpm at which any tone band from 10,000 cycles down was driven. This indicates the absence of any frequency characteristic from 10,000 cycles down to the region in which the arm resonance occurs.

Reference

1. Characteristics and Aircraft Applications of Wire Resistance Strain Gauges. A. V. deForest. *Instruments*, volume 15, April 1942.

Technique of Electrical and Hydraulic Testing of Hydroelectric Units

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MEMBER AIEE

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Synopsis: The application of the AIEE Test Code for Synchronous Machines in field testing of hydroelectric generators is discussed, and the preferred method of making certain tests is indicated, together with reasons for its selection. Methods of making acceptance tests on turbines are outlined in sufficient detail to establish the fundamental theory, and the electrical measurements on the generator required to establish the generator input for the hydraulic test, are listed, with brief reference to the accuracy required, and to means of obtaining it. Rating and other hydraulic tests on hydroelectric units are also described.

ALTHOUGH commercial or acceptance testing of hydroelectric units has been the rule rather than the exception, very little has been written of the technique, especially of matters peculiar to field testing. The Test Code for Prime Movers of the American Society of Mechanical Engineers,[1] has been available for some years, and the AIEE Test Code for Synchronous Machines[2] was approved recently. The latter "provides in convenient reference form the more generally applicable and accepted methods of conducting and reporting tests of a commercial nature, which apply to the fulfillment of performance guarantees and to acceptance tests." This code serves a very useful purpose, permitting manufacturer and purchaser to agree on methods of conducting tests, and avoiding the necessity of specifying in detail how performance guarantees may be determined. It is the purpose of this paper to discuss:

1. The application of the Test Code for Synchronous Machines to field testing of hydroelectric generators, noting especially which methods given in the code can be used, and why alternative methods are unsuitable.

2. Certain aspects of field testing of hydraulic prime movers.

3. The frequent necessity for making electrical measurements on the generator when the primary test is on its associated turbine, and the method of measurement and accuracy required.

It is not the purpose of the paper to record methods of making either electrical or hydraulic tests where the technique is routine and straightforward, and presents no difficulties other than those usually present when tests are made on any generator or its prime mover.

Paper 46-70, recommended by the AIEE committee on power generation for presentation at the AIEE winter convention, technical meeting, New York, N. Y., January 21-25, 1946. Manuscript submitted November 26, 1945; made available for printing December 13, 1945.

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Electrical Tests

General

In the great majority of cases, hydroelectric generators are erected on the site. The stator iron and complete stator winding in the larger units are often assembled in the field, and field poles mounted on the rotor spider or rim. Even when the above operations can be performed in the factory the assembly of the unit is of necessity a field job, and any tests on the completed generator must be performed at the site, after erection is completed. This situation produces the first peculiarity in testing under field conditions, in that the facilities for testing may be, and usually are, restricted greatly, compared to those usually available in the factory. Restrictions may be imposed by units already in routine operation in the plant, by construction, and because the generator is permanently connected to its bus, and in fact, may have been in commercial operation before certain of its acceptance tests are made. The site may be many miles from the factory, and from the utility's laboratory. It is, therefore, essential, before proceeding to the site to make the required tests, that the specification be carefully examined, the tests to be made listed, and the methods of making them discussed. It is of the utmost importance to list all portable instruments likely to be required, of such ranges as will accommodate the potential and current transformers associated with the generator. It is very seldom necessary to provide special potential or current transformers for routine acceptance tests. Where tests of a special nature are included, it may be necessary to devise special equipment to obtain the desired measurements. All this work should be done, if possible, before the tests are started; otherwise a great deal of time may be lost, or one or more tests may have to be abandoned for lack of the proper equipment for making them.

Resistance Measurements*

Hydroelectric generators, except for units of low kilovolt-ampere rating, have very low armature and field winding resistances. Special artifices are often necessary to obtain an accurate measurement of resistance. The voltammeter method is usually employed, as use of the Kelvin bridge is not practicable for field measurements. Battery voltage and low range voltmeter have been found to be satisfactory, with the usual precautions. If the armature winding is two, three, or four circuit, as is frequently the case, each circuit can be measured separately, or all windings in one phase may be connected in series and the voltage drop across each measured. Temperature detectors almost always are specified for the hydroelectric generator, and are used to measure the winding temperature. Care must be taken to have the generator in thermal equilibrium at the time resistance measurements are made. The test current must not be so great that the winding temperature is affected by the copper loss due to the current.

The field resistance at a known temperature is required for the following reasons:

1. To determine accurately the field I^2R loss.

2. To determine the temperature rise of the field.

3. To calibrate the field temperature indicator if such is provided.

The voltammeter method should be used to make this measurement, as the "hot" resistance, of necessity, must be determined by this method. The measurement of temperature of a winding by its change in resistance requires that every source of error be minimized. The cold and hot resistances should be measured with the same instruments, and with deflections on the instruments of the same order of magnitude.

Telephone Interference Factor

Although hydroelectric generators of modern design have a telephone interference factor low enough to prevent disturbance in telephone circuits, it is possible that disturbing harmonics inadvertently may be present in the voltage wave. Conditions at some remote point, where a power and communication circuit are in-

* The sequence of these notes has been made generally the same as in the Test Code for Synchronous Machines.

volved in a parallel may be magnified by the presence of these harmonics. Measurement of the telephone interference factor is recommended where equipment is available to determine this factor, especially if the design of the generator winding is limited in freedom of choice to the point where it becomes difficult to eliminate undesirable harmonics.

Phase Characteristic Curves (V Curves)

These curves offer the best method of determining the excitation values at all loads and power factors. As discussed later under load excitation, the zero power factor saturation curve used with the open circuit saturation curve to obtain the excitation characteristics is always difficult and often impossible to obtain. It is not usually possible to set the voltage, load, and power factor at exactly the value desired when the unit is operating on the system. Small deviations from the desired values, especially in power factor, cause relatively large changes in field current. The phase characteristic curve permits greater accuracy in the determination of excitation under any condition of load, provided the voltage can be held close to normal value.

Line Charging Capacity

This characteristic may be important in the case of hydroelectric generators because the units are usually associated with a transmission network of high-voltage lines. Voltage must be built up on a line for line testing, and the generator should have sufficient line charging capacity to permit this without becoming self-exciting. Self-excitation is an unstable condition, leading to high and uncontrolled voltage on the generator and system being tested. Excitation can be reduced to zero on a hydroelectric generator with safety, and even made slightly negative, with the generator under test connected to the system. Provided the kilovars taken by the generator are not large enough to disturb system conditions, the ability of the generator to supply line charging kilovars thus can be determined exactly.

Load Excitation

It is frequently difficult or impossible to obtain a saturation curve at zero power factor and rated amperes on a hydroelectric generator. The difficulty arises because it is impossible to circulate full load current between one generator and another of equal size, even if both can be synchronized on the same low-voltage bus. It is sometimes possible to synchronize the generator with the system, and obtain one or perhaps two points on the curve at or near normal voltage. A third point is available at zero voltage from the short-circuit impedance curve. Such meager data are insufficient to plot an accurate zero-power-factor saturation curve.

As stated earlier in this paper, the use of the phase characteristic or *V* curves, which can be determined readily, is recommended.

Sudden Short-Circuit Tests and Synchronous Machine Quantities

The 3-phase sudden short-circuit test at rated voltage should not be omitted on a large machine of new design, as mechanical failures due to inadequate bracing of the stator winding are known to occur. If oscillograms are taken, the transient and subtransient reactances and their time constants can be determined. The determination of these reactances and time constants by test gives valuable information to both designer and user.

Very little information is available on the suitability of the test methods for determining other synchronous machine quantities. Those that have been tried in the field have given only fair results. There is need for an exchange of information among those interested covering the technique to be used. The instructions in the test code appear to be insufficient, and need to be proved in the field. Such tests are in a comparatively new field in testing of hydroelectric generators, although the value of a knowledge of these quantities in estimating the performance of a generator has been appreciated.

Losses

Several methods for measuring generator losses are listed in the Test Code (page 13 and those that follow). Only the retardation method has been found uniformly successful for hydroelectric units. The separate driving motor, calorimeter, cooler method, and input-output method are either impractical or require special facilities and time for execution. The electrical input method has been used, not because it was satisfactory, but because the retardation method had not been developed to the present degree of accuracy. This method requires special low-ratio current transformers, which are often difficult to mount in the leads from the generator, especially if these leads are of cable, brought out to a metal-clad bus structure. It is impossible to prevent hunting between driving and driven units, and great care is necessary to obtain a consistent set of readings. Harmonics are usually present in the current wave, and may increase the error already present from other causes. There is great danger of the units falling out of step if the voltage is lowered to a point where synchronizing power is insufficient. If this condition should develop, a heavy overload is placed on the metering current transformers, and these may burn out before they can be protected by closing their short-circuiting disconnects. The measurement of stray loss by this method is involved, and the accuracy doubtful. One major source of error arises in the use of high-ratio current transformers and low-power-factor current, giving current transformer errors and errors due to small deflections on the wattmeter used. The latter error may be decreased by using a low-power-factor wattmeter. The use of the electrical input method, at least for medium or large units, is not recommended, unless no other method can be used.

The retardation method depends for its accuracy on careful determination of the Wk^2 of the generator, and of the speed-time curve, both of which are essential for the calculation of the loss under any given condition.

A very close approximation of Wk^2 of the generator can be made for the rotor of a water-wheel generator. The weight of each salient pole is known accurately,

Figure 1. Gibson diagram from differential test of 66,000-horsepower unit

and the weight of the rim is also capable of accurate calculation from drawings. These calculations can be checked by test, using one or more of the methods outlined in the test code.

Use of the d-c generator separately excited, with biased output voltage (see test code, pages 18–19) has proved most successful for measurement of speed. The measurement must be made carefully, and frequent checks made during the progress of the test to prove the constancy of the calibration. This method of speed measurement is given in detail in the test code, and need not be repeated here.

The calorimeter method of determining losses[3] is applicable only to totally enclosed hydroelectric generators. Unless the temperature of the ambient air can be closely controlled, as in the case of the totally enclosed generator, it is extremely difficult to relate the temperature rise of the air to the loss or losses causing it, due to the thermal capacity of the generator. The increase in number of this type of

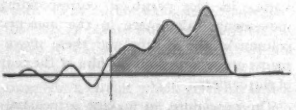

Figure 2. Delineation of area on Gibson diagram measuring impulse

Actual length of hatched area 7.75 inches or 10.6 seconds

Maximum height 4.4 inches, equivalent to 4.80 feet of water

Average height equivalent to 2.65 feet of water

generating unit permits use of this alternative method of loss measurement. Its chief disadvantage is the time required for a complete set of tests. A crosscheck can be obtained on the total losses, by operating the generator at rated load and measuring the temperature rise of the cooling air. The individual losses also can be measured, and windage separated from friction loss.

The segregated generator losses are used to establish the generator efficiency, and also are used to determine generator input on the acceptance test of the prime mover. Their use in this latter respect is discussed in some detail later in this paper.

Hydraulic Tests

This section of the paper deals chiefly with the acceptance tests of the prime mover and the rating test of the hydroelectric generating unit. The acceptance test is that having as its objective the determination of whether or not the unit and its component parts satisfy the guarantees of capacity, efficiency, and reliability made by the manufacturers. The rating test determines the efficiency of the unit as a whole, and the variation in efficiency, in order that the most effective use may be made of it along with other units in the same power plant and with other plants in the same system.

The acceptance test of necessity considers the component parts of the unit separately, that is to say the generator and turbine independently of each other. The discussion will not extend to other parts such as the governing system, and water passages except incidentally. The rating test on the other hand considers the unit as a whole including not only the turbine and generator but conduits and other water passages serving that unit and no other.

For tests of both kinds, three primary quantities must be measured, namely, the power, the flow, and the head. The flow is the same whether one is considering the acceptance or the rating test, but power and head are not. In the acceptance test of the turbine the output power is the same as the input to the generator shaft and therefore includes the generator output and all generator losses while in the rating test the power is the net output of the generator. The head in the acceptance test is determined from measurements made as close to the turbine as practicable. In the rating test the head considered is the difference of elevation of forebay or headpond and tailwater.

Accuracy

At this point the authors would like to comment on certain features of the precision required in test equipment and observations. Insofar as the acceptance test is concerned, test codes of various associations and technical societies define in greater or less detail the method in which various quantities shall be measured and the acceptable degree of precision. No such criteria exist, however, to govern accuracy in rating tests. The responsibility of securing the results required at a cost no greater than is warranted by their value rests with the engineer in charge of the tests. It is the authors' considered opinion that as great accuracy is necessary in the rating tests as in the acceptance test where the representative of the manufacturer carefully scans the details of all arrangements for the test and all observations in order that the final result for efficiency may not fall

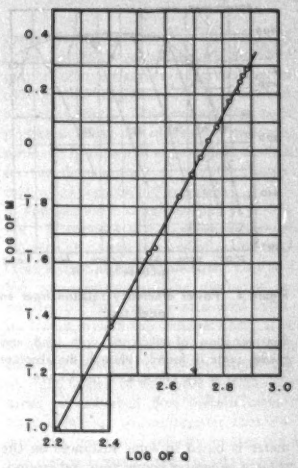

Figure 3. Relation of discharge to pressure differential between piezometers in penstock and scroll case of turbine

M = differential pressure, feet of mercury
Q = discharge, cubic feet per second

so much as a tenth of one per cent below the maximum that can be shown honestly.

Because of their ready availability, there is a tendency to substitute switchboard meters, gauges, or instruments of low grade for test instruments of high precision and accuracy, and to use observers unskilled in tests and investigations of this type. In consequence of this, unreliable or misleading results may be secured and incorrect conclusions reached. The authors call to mind certain specific incidents that justify this criticism.

The acceptance test of the turbine and the rating test of the unit frequently are made at the same time. It is convenient therefore to give a single description of measurements and procedure applying to both. This description will be divided into three parts, each part dealing with one of the three primary quantities to be measured.

Measurement of Power

For the rating test the quantity to be measured is the output of the generator. The authors have been associated in many tests and have used instruments of various types. In general the instrument preferred is a calibrated polyphase wattmeter. Exception may be taken to this instrument and in fact many test codes require that single-phase meters be used. The objection to the use of the polyphase

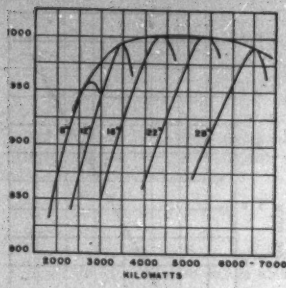

Figure 4. Power efficiency relation from an index test

The variation of efficiency with load and blade angle is found although the absolute value of the efficiency is not known

meter is based in some instances on the type of generator connection and grounding. The objection does not apply in the case of the plants operated by the organization with which the writers are connected and the advantages of using a single instrument are so evident that it is to be preferred wherever it is properly applicable.

In the acceptance test of the turbine, its power output is required. Where the turbine and generator are mounted on the same shaft, the turbine output is the generator output plus the generator losses. The accuracy required makes the method of dividing the generator output by generator efficiency unsatisfactory, although the authors have found it necessary on occasion to do this, on generating units of small size, where insufficient data were available to enable generator losses to be computed.

If generator losses have been measured on the unit under test, readings of generator voltage, stator current and temperature, field current, and exciter outputs, on each test run, will permit an accurate computation of individual losses. These can be added to the measured generator output. The precision of measurement of the losses is very high, compared to the measurement of generator output, so that it is possible to use losses as measured on a duplicate generator, or even to use the generator designer's estimate of losses, without introducing an error large enough to have any noticeable effect on the overall result.

Calibrated portable instruments of high standard should be used for the electrical measurements. The instrument transformers associated with them should have a known ratio of transformation. Otherwise they should be calibrated. In at least one instance a calibration of the instrument transformers requested by the representative of the turbine manufacturer disclosed errors that were quite unsuspected until the calibration had been made.

The importance of this test on occasion may justify duplicate measurement of power by independent observers, using separate instrument transformers and wattmeters calibrated against different laboratory standards.

Measurement of Flow

The accurate measurement of the quantity of water flowing through the turbine is one of great difficulty. Various methods of measurement are available, the choice of method depending on the particular situation in hand. Four of these methods will be described briefly. Complete descriptions of all of these considered herein are available elsewhere; hence descriptions are carried only so far as to make clear the comments on their fields of application and reliability.

The Gibson Method[4]

The Gibson time-pressure method of measurement of flow is an invention of Doctor Norman R. Gibson, and an outcome of his extensive studies of pressure-rise in hydraulic pipe lines. The method, simple in principle and fundamentally sound, is an application of the second law of motion, expressed briefly as

$$Pt = m(v_1 - v_2)$$

When a column of water flowing in the penstock of a hydroelectric unit is brought to rest by closing the turbine gates, a force is impressed on the water column in bringing it to rest. Assuming that the mass of water has its velocity changed to zero during gate closure, the change in momentum effected is the product of the mass of the water in the penstock and the original velocity. This change in momentum is equal to the impulse causing it, that is to say, the mean value of the force acting upon it to bring it to rest multiplied by the time during which it acts. Of these four quantities, force, time, mass and velocity, three can be measured and the fourth, the velocity, computed, it being the only unknown in the equation.

Equipment was devised by Gibson to measure the force or pressure acting on the water column by a mercury U-tube, and to record the pressure variations on a moving film. The equipment, with minor changes, has been used by nearly all, if not all, investigators on this continent. German scientists working mainly with Doctor D. Thoma at Munich built instruments in which pressure changes deflected a mirror through the movement of a spring-controlled piston. A beam of light of high intensity focused in the mirror is reflected through lenses to a photographic paper moving past a narrow slot. Comments on both of these types of equipment will be made later.

The Gibson instrument consists of a camera at the front of which one leg of a mercury U-tube is clamped at a definite distance from the lens. The U-tube is connected to the penstock, and the level of the mercury in it is a measure of the pressure in the penstock. At the rear of the camera is a photographic film on a cylinder which is rotated at a speed suited to the rate of closure of the turbine gate. Between the U-tube and the lens, a pendulum is arranged to cut off the light passing through the U-tube once every second. Illumination for exposure of the film is provided by a bank of photoflood lamps. The instrument is so constructed that no light can reach the film except that passing through the U-tube. As the pressure varies in the penstock corresponding movements take place in the mercury column in the U-tube and these movements are recorded on the film at the rear of the camera.

The procedure, in making a measurement of flow in a penstock, is as follows: The unit under test is loaded to the point at which it is desired to measure the discharge and sufficient time allowed for operating conditions to become satisfactorily steady. On signal from the operator at the Gibson instrument, the turbine gates are closed at a uniform, predetermined rate, during which time, and for a few seconds before and after, the moving film in the camera is exposed recording the rise and fall of the mercury column in the U-tube, and therefore the changes in pressure. From an analysis of the exposed film an area is delineated which measures the impulse bringing the mass of water in the penstock to rest. The measurements are repeated for a series of similar runs covering the whole range of capacity and flow for the turbine.

Originally it was the practice to have a connection to the penstock from one leg only of the U-tube, the other leg being carried to a sufficient height to balance the penstock pressure. The mercury column was often of great height, 20 feet or more in some tests conducted by the authors, which introduced certain difficulties in conducting the tests. It made it necessary also to secure, in synchronism with the Gibson diagram, a graphic record of the variations in headwater level.

It is the practice now, whenever possible, to connect both legs of the U-tube to the penstock at sections so far apart as to secure a diagram of satisfactory area on the film. The test made with a single connection is known as a simple test, that with two connections to the penstock as a differential test.

In Figure 1, a diagram from a differential test is submitted. The dimensions of the original are marked on the figure to give a better idea of the scale. In Figure 2 is shown a copy of this diagram with the area representing the product of pressure and time crosshatched. It is not intended to discuss here the method of determining the lower and left hand limits of the area, but this explanation should be made:

The regular waves following the end of the diagram result from the fact that the mercury column swings up and down in the tube until friction brings it to rest at its final static level. They are not due to pressure variations in the penstock. These after waves enable the end point of the diagram to be determined in most cases. The author has found it necessary for tests of plants with very short supply pipes to have a contact, closed by the servomotor piston at the end of its stroke, complete a circuit which gives an indication in the film of the completion of closure of the turbine gates.

The instruments made by Volkhardt and Deckel and used at Munich, Eitting, and Heidenheim, are much more complicated than the instrument by Gibson. One of the advantages sought in their design is the elimination of effects due to the inertia of the mercury column. This inertia, however, has certain compensating advantages, Thoma points out, enabling a more precise determination of the end point of the diagram, in certain instances, than the instruments with spring controlled pistons. Special provision is made to overcome the effect of friction. Calibration is difficult and liable to change. However, they are instruments of great precision.

Deckel submitted the results of tests by his instrument made at Munich in 1930 in which the average difference from the measurement by a calibrated weir was 0.41 per cent, only 2 runs out of 14 showing errors exceeding one per cent. Deckel's comments on the method are interesting in that other methods of measurement have found greater favor generally in the institution in which his work was done:

"The Gibson measurement process in many cases offers considerable advantages as compared with other measurement methods. These advantages are based on the practical simplicity and good theoretic foundation for the process. It must be provided, of course, that its grade of accuracy is not below that of other processes, that is, the possible error should not exceed one per cent when compared with the highly developed stage of present measuring processes . . . The tests which were carried out will confirm this."

Allen Salt-Velocity Method[5]

Professor C. M. Allen of Worcester, Mass., has, by his research, brought to a high degree of precision the measurement of flow by observations of the time for a charge of brine to pass from one section to another in a penstock. In this method the charge of brine is injected through one or more special valves suitably disposed on the cross section of the penstock and the time for it to move from the point of injection to a cross section further downstream is measured. At the lower cross section a series of electrodes is set up in the penstock and the time of passage from the point of injection to the electrodes is determined by a graphic measurement of the change in conductivity of the water, the time being accurately measured on the chart as well as conductivity. The method is adaptable to situations where the cross-sectional area of the penstock is irregular or where velocities are extremely low and other cases where the Gibson method is not readily applicable. Its disadvantages are that the disposal of the injection valves and the electrodes on the cross sections require considerable experience with this type of test. A more or less prolonged shutdown of the unit is necessary also to install the equipment.

The necessity for experience in the design of the equipment and its disposal on the cross section will be realized when it is remembered that the charge of salt coming through a valve at the center of the penstock moves downstream at a greater velocity than a charge injected at the side of the penstock. It is therefore necessary to design the equipment so that the average time of passage from one cross section to the other will be recorded correctly. The authors have attempted to use the method on one occasion and from the difficulties experienced in securing satisfactory results in that instance have some appreciation of the vast amount of effort that has been put into the perfection of the method by Professor Allen.

The Current Meter[6]

The third method to which reference will be made and one that has been used perhaps more frequently than any other, is the current meter method. The method has been brought to a high degree of accuracy for measurement of discharge of power houses through the work of a large number of investigators in North America commencing with the work of Groat and Nagler in 1912. The method has been preferred above all others for measurements in Europe and a great deal of work on the development of suitable instruments has been carried out there.

The method is simple enough in principle. It consists of the measurement of velocity at a large number of points on a cross section at the intake of the unit and the computations of the discharge by multiplying the average measured velocity by the area of the cross section. The necessity for refinement comes about because the velocities at any section are not at right angles to the cross section. In areas of disturbed flow certain meters have a tendency to over-register, that is to say, they measure a velocity greater than the resolved part of the velocity normal to the measured cross section. Other meters under-register, some to a greater degree than others. By using groups of meters of different types in a test and comparing the results, each with the other, the correct normal velocity may be determined.

The method is readily adaptable to cases where a very short supply pipe leads to the turbine, therefore making it difficult to apply the Gibson or Allen methods. As just indicated the common European practice applies the current meter method in nearly all instances, in fact it has been used frequently in Europe to measure the velocity on the cross section of a penstock

Figure 5. Bank of gauges used for index test

These are simple water columns under compressed air to depress them to the range of the scales

where in North America one of the other methods would be applied.

The Weir

In some instances it is possible to install a weir in the tailrace of the plant. Measurement of discharge by a weir is only possible in cases where the discharge is moderate, that is to say, not more than two or three hundred cubic feet per second and where the reduction in head resulting from the installation of the weir is only a small percentage of the total head.

Measurement of Head

The third of the primary quantities to be measured is the head acting on the turbine or on the plant. There is, of course, a distinction between these, sometimes of considerable magnitude, for example, in the case of a plant having a long penstock. For low-head plants the difference is not so marked. For the purpose of tests, the simpler the equipment, the more satisfactory it is for measurement of water level. In the forebay or tailrace of a plant, simple float gauges are preferred installed in float boxes connecting with the body of water, the surface elevation of which is to be measured, by a small opening in the float box which dampens surges. The usual practice in the rating test of a generating unit is to install at least two of these in the forebay and two in the tailrace, usually in the stop log checks.

In the acceptance test of the turbine unit, however, the head must be measured at the entrance to the turbine casing, and in a plant having a long penstock the head measured at this point will be appreciably different from that measured in the forebay. Bourdon gauges are unsatisfactory for this purpose and a mercury manometer is preferable even though this may be of great height, requiring two observers to read it. A case in point is a plant on which a test was made recently where the operating head was 340 feet and the mercury manometer about 24 feet in height.

In the case of the acceptance test, as indicated previously, the pressure head is measured at the entrance to the turbine casing. To the pressure head, plus elevation head at that point, there must be added the velocity head in the penstock. The net head acting on the turbine is the head at entrance to the casing, expressed as an elevation, minus the sum of tailwater elevation and the velocity head at the section at which the tailwater level is measured. In some instances, however, the velocity head in the tailrace is neglected. In the case of the rating tests of the plant the gross head only is to be considered, that is to say, the difference of level in the water in the forebay and in the tailrace.

Frequently gauges measuring these water levels are installed to give an indication in the control room of the levels, and it is most desirable to check these gauges during the tests, not only for correctness in their indications, but also for the correctness of indication by them of the true forebay or tailrace level. The location of the actuating element of the gauge is frequently such that it is affected by local disturbances and by variation in load on the particular unit near which it is installed. It is the authors' practice to observe the operations of such gauges carefully during the test in addition to making observations on special gauges installed for the test itself.

In addition to the primary measurements dealt with in the three preceding sections, a number of other quantities are observed such as gate opening of the turbine and information that will enable segregation of the hydraulic losses in the water conduits to be made.

Analysis of Data

Having computed the three primary quantities, power, head, and discharge, for each run, these are tabulated and corrected for departure of the test head from the rated head of the unit. In the case of the acceptance test, capacity and efficiency of the turbine will be given by the turbine builder for some specific head. In the tests the actual head will differ from this slightly, and power and discharge for each of the runs will be corrected to that which would have been realized had the test been made at rated head. This correction can be made without impairing the accuracy of the results provided that the test head does not differ by more than three or four per cent from the rated head. The results are then plotted in the form of a power-discharge curve. Two additional curves are plotted also, namely, the power on a base of gate opening, and discharge on a base of gate opening. The three curves are then compared and adjusted until all three are in agreement. From this point on practically all of the results secured regarding capacity and efficiency will be based on the three curves, particularly the power-discharge curve. It is customary to compute the efficiency of the unit from the adjusted power-discharge curve and not from the individual test runs.

A similar set of three curves will also be drawn based on the gross head of the plant and the generator output, these forming the basis of a report on the rating test of the plant.

Rating Discharge Against Differential Pressures

It will be appreciated from the description of the various methods of measuring the quantity of water flowing that this part of the test is difficult and expensive and may involve serious interruptions to operation of the unit. It is desirable therefore to secure records that can later be used to measure the discharge with less inconvenience and expense. The author used such a method some 23 years ago at the Queenston plant on the Niagara River by observing the reduction in head from forebay to a point at the entrance to the casing of the turbine, using a mercury manometer for the purpose. The reduction in pressure head was largely due to the great increase in velocity head at the lower measuring point and was a function of the magnitude of the flow of water in the penstock. The ratings so made in the original tests by the Gibson method were later used in tests which involved simply a measurement of the difference in the pressure head at forebay and scroll case, to determine the flow. It is common practice now to install piezometer connections at suitable points in the penstock and scroll case and to determine, at the time of the original tests when the flow is measured by one of the methods described above, the relation of the discharge to the differential pressure between two of these piezometers.

The results of such a measurement in a turbine test made recently are as shown in Figure 3. The flow was measured by the Gibson method and the differential pressure was read on a differential manometer connected to a piezometer in the speed ring and a ring of four piezometers around the downstream end of the penstock. It is only necessary at any future time to measure the differential pressure to determine discharge from the data submitted in the graph. The relation is unaffected by head, the condition of the turbine runner or other changes beyond the piezometers.

Index Tests

When, for physical or economic reasons, it is unadvisable to make discharge measurements, it is still possible in many instances to secure records of variation of efficiency of a turbine unit by measuring quantities, the variation of which with the discharge is known, approximately, if not exactly. Tests in which such quantity is measured instead of the discharge are known as index tests. From them, the power and head being measured, it is possible to derive efficiency curves which show the variation of efficiency with load but not the absolute value of the efficiency.

To illustrate: In order that the governing mechanism of a Kaplan turbine may be so designed as to secure the highest efficiency at all loads, information must be available as to the variation of efficiency with gate opening, or load, and blade angle. The quantity related to the discharge, which is measured is a pressure differential between two piezometers suitably disposed. The discharge varies approximately with the square root of the differential pressure and the efficiency therefore with the kilowatts divided by the square root of the differential pressure. In Figure 4 such a series of curves derived from a test of a Kaplan runner is shown, each curve being for a specific blade angle.

The envelope of these curves provides the information for the design of the cam which properly correlates gate opening and blade angle. Forty or more separate measurements of discharge would be required to develop the five efficiency curves shown in Figure 4. The gauge, or series of gauges set up for the test, is shown in Figure 5. Readings in this case were taken on water columns depressed by compressed air to a reading range. The various gauge columns are connected to piezometers in penstock and scroll case.

Conclusion

In conclusion, it may be stated that a definite policy of making tests on both generator and prime mover, even if considerable expense and effort is involved, undoubtedly will pay dividends. These tests make quantitative data available, the value of which may not be apparent at the time the tests were made. However, it later may make possible an engineering solution to some difficult problem of operation, or point the way to improvement in performance in the unit tested, or succeeding ones in the same or other stations.

References

1. Test Code for Hydraulic Prime Movers. American Society of Mechanical Engineers, June 1938.

2. AIEE Test Code for Synchronous Machines. Number 503, June 1945.

3. Calorimeter Measurement of Stray Load Losses of 55,000-Kva Generator Having Enclosed System of Ventilation, G. D. Floyd, J. R. Dunbar. AIEE Transactions, volume 51, 1932, pages 12–18.

4. The Gibson Method and Apparatus for Measuring the Flow of Water in Closed Conduits, Norman R. Gibson. American Society of Mechanical Engineers *Transactions*, volume 45, 1923, page 343.

5. The Salt Velocity of Water Measurement, Charles M. Allen, Edwin A. Taylor. American Society of Mechanical Engineers *Transactions*, volume 45, 1923, page 285.

6. Water Gauging for Low Head Units of High Capacity, J. M. Mousson. American Society of Mechanical Engineers *Transactions*, volume 57, 1935, page 303.

Dielectric Recovery by an A-C Arc in an Air Blast

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SINCE the extinction of the arc drawn upon opening an a-c switch depends upon a rapid transition of the arc near a normal current zero from a conducting to an insulating state, much study has been given by switch designers to this transition, often referred to as dielectric recovery. However, the published experimental data with regard to the mechanism of this dielectric recovery still are meager and there is no generally agreed upon theory, even for the simpler cases. One simple case, of growing importance in this country, is that of the arc in an air-blast circuit breaker. Perhaps the simplest arrangement is found in the nozzle type of air-blast breaker variously described as radial blast or axial blast. Figure 1 is illustrative of such nozzles, somewhat reduced from practical forms.

Of particular value for the understanding of the arc extinction processes are curves showing the rise of the arcs reignition voltage, or dielectric strength, with time during the first few hundred microseconds following arc failure near a normal current zero. There have been several attempts to predict the course of such curves for the air-blast breaker, of which that by Kesselring and Koppelmann[1] is noteworthy for its completeness. Some direct experimental results defining a single curve and indicating another have been presented by Prince, Henley, and Rankin[2] for a cross-blast or splitter type of breaker at greatly reduced air pressure and unstated current. Also presented by Prince were some very interesting high-speed moving pictures of the arc in a splitter type breaker, but these, like earlier ones presented by Biermanns[3] for the nozzle type breaker, are somewhat inconclusive. These photographs and the theoretical picture of arc interruption in an air blast have been further discussed by Slepian.[4] In the theory of Kesselring and Koppelmann and others a physical cutting and progressive displacement of the permanent arc core is presumed. Slepian, in agreement with earlier discussions by Mayr,[5] has preferred to ascribe the dielectric recovery of the arc space to cooling and ion diffusion, and has pointed out the decisive importance of turbulence of the gas motion in enhancing the diffusive effects.

In the course of an extended experimental study by the writer of the factors influencing arc extinction in models of air-blast orifices like those of Figure 1, a considerable mass of data has been obtained, including 16 more or less complete curves of dielectric recovery with time by the arc space under widely varying conditions. Some of these results will be presented and briefly discussed in the light of existing theories.

Paper 46-21, recommended by the AIEE committee on protective devices for presentation at the AIEE winter convention, New York, N. Y., January 21–25, 1946. Manuscript submitted November 9, 1945; made available for printing December 13, 1945.

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Experiments

The nozzle and contact arrangement shown in section in Figure 1A is typical of the earlier forms studied. This sketch shows the location of arc resisting inserts of copper-tungsten and soapstone as generally used, these being omitted in the other sketches for simplicity. In all of the work to be described the orifice diameter was 0.765 inch and the arc was drawn by rapid downward motion of the lower (upstream) contact through the orifice to the open position shown. Compressed air from a storage tank was introduced into the annular space between the supporting fiber plates through a poppet valve, piping, and entrance orifices which reduced the steady-state gauge pressure at the interrupting orifice entrance to between 0.7 and 0.8 of the initially adjusted tank pressure. Beyond the arc space the discharged air passed through openings having $3^1/_4$ times the area of the main orifice, resulting in a pressure elevation on the discharge side of the orifice roughly 1/10 the entrance-side gauge pressure without arcing and up to two or three times this in the presence of a one or two thousand-ampere arc.

Of all the orifice arrangements tried, that of Figure 1B proved to be the most efficient in terms of required air pressure for interruption of low power factor currents up to 2,200 amperes at 13,800 volts

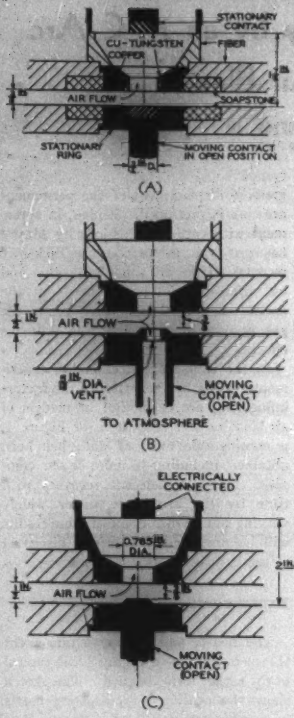


Figure 1. Experimental air-blast orifices

and 4,200 amperes at 6,900 volts, the maximum values available for these tests. Interrupting test results with this orifice are plotted in Figure 2A. The upper broken line is drawn through points representing tests at the maximum gauge pressure in the tank at which a failure to interrupt occurred and the lower line through points of minimum gauge pressure in the tank for a successful interruption. Interruptions were considered successful if not more than one cycle of arcing (at 60 cycles per second) occurred after passage of the electrode tip through the orifice. These limits were always checked by obtaining at least four tests just outside the limits all of which were either successful or unsuccessful. Thus, the region between the lines is one of uncertainty separating regions of high and of low probability of interruption. Figure 2B is a similar plot for the orifice of Figure 1C, which was a much less efficient interrupter, especially at the lower currents. The favorable features combined in the Figure 1B orifice were indicated step by step in a long series of tests leading up to it. They are principally:

1. Rounding of the edges of the orifice and contact rings to minimize electric stress concentration.

2. Proper spacing of the contacts relative to the orifice.

3. A slight crowning, or beveling of the upstream contact face.

4. Insulation of the metal orifice ring from the downstream contact.

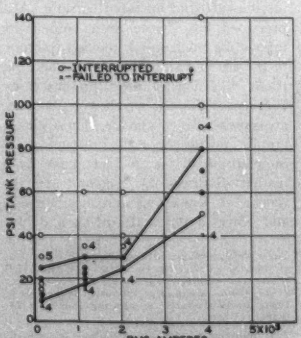
5. Venting to atmosphere of the center of the upstream contact face through a smaller auxiliary orifice.

These features are in close correspondence with those of an orifice-type high-voltage compressed-air circuit interrupting element developed by Ludwig and Baker.[6] The orifice of Figure 1C, lacking only features 4 and 5 of the preceding list, was chosen for an extended study of dielectric recovery with time because its inferior performance permitted it to be tested adequately over a much wider range of pressures and currents than would have been possible with the Figure 1B orifice. Also, the Figure 1C orifice is itself of practical interest, since its simpler construction permits its use in simpler and more compact circuit breakers, especially those for the lower voltages.

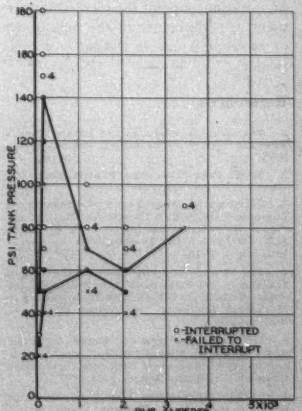
Figure 3 shows some of the information leading up to the Figure 1B type of orifice. These data were replotted from families of curves like those of Figure 2, using points from the upper limit curves only. These maximum failure pressures are plotted in Figure 3A as a function of the spacing of the downstream contact, in this case a copper-tungsten tipped 1/4-inch rod, above the open position of the upstream contact face. For convenience in interpretation, the orifice and electrode sections are dotted in to the scale of the spacing co-ordinate with the plane of the upstream contact face at the origin. Smooth curves are drawn through the somewhat scattered points for each of the three currents, 175, 1,100, and 2,000 amperes, all of these tests being at 13,800 volts. It may be deduced from the slopes of these curves that the region near the flow constriction, or "vena contracta," is of most importance at all currents but was practically the only effective interrupting region at the higher currents. At 175 amperes, the axial region beyond the orifice was of lesser but still of considerable importance. Figure 3B is a similar plot of results of tests in which the projection into the orifice region of a 1/4-inch stud from the center of the upstream contact face was the varying parameter. These curves similarly show a more sharply restricted interrupting region for the higher currents. The minimum near 3/16-inch projection for the 175-ampere curve probably also points to the advantage of a somewhat pointed or crowned shape for the upstream contact face.

In all of the work just described the testing circuit was used without modification of its normal transient characteristics, the natural frequencies and decrements of the recovery voltage oscillation components varying with the particular circuit adjustments, particularly with the short-circuit current settings.

Figure 2. Interrupting pressure range as a function of current



A—Orifice of Figure 1B



B—Orifice of Figure 1C

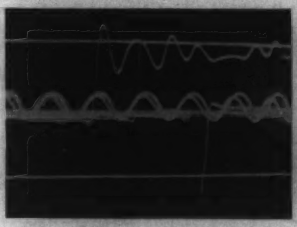
To get direct information about the course of the dielectric recovery in the arc space with time, the natural frequency of the circuit, or its rate of rise of voltage, was controlled by capacitor shunts in parallel with the arc, and the reignition voltages appearing across the arc terminals were measured from cathode-ray oscillograms. Figure 4 shows four samples of such oscillograms, taken by photographing the screen of an RCA 904 cathode-ray tube with a miniature camera. The beam was oscillated magnetically at power frequency with such phase and amplitude that it passed across the screen only during each recurrence of a small time interval embracing each current zero moment. At this time the rate of change of the deflecting magnetic field and so the speed of the beam was nearly constant. Voltage calibration was provided by superimposing the horizontal lines resulting from application of open circuit voltage (these being the positive and negative peaks of the voltage waves), and time calibration by further superimposing a small amplitude trace produced by a calibrated oscillator.

The oscillograms in Figure 4 of tests 12,417 and 12,440 show, successively, the effect on the reignition transients of a 175-ampere arc with 20 pounds per square inch air tank pressure of adding a small (0.035 microfarad) shunting capacitor. Wide variations in reignition voltage and time at successive current zeros are well illustrated by the three reignition traces in test 12,440. The smallest value (of negative polarity) probably occurred before the contacts were fully open. The oscillograms of tests 13,110 and 12,848 each show two arc reignition transients followed by an extinction transient, the currents interrupted being 1,070 amperes and 2,260 amperes, respectively. In test 13,110 the circuit, containing an air-core reactor, was unshunted and in test 12,848 a delaying shunt of 0.102-microfarad capacitance was added.

The results of a long series of such oscillographic measurements of tests with the Figure 1C type orifice were plotted and are shown in Figure 5. In addition to the reignition voltage points marked with open circles, in many cases the peaks of recovery voltage transients which did not cause reignition (extinction voltages) were also plotted and marked with solid circles. Where possible, envelopes were drawn enclosing the estimated regions of uncertainty within which most of the breakdowns occurred. Low breakdown points near or outside the envelopes, when indicated by adjacent question marks, were judged probably to indicate breakdowns at less than maximum contact separation. The dotted lines through the origin are lines of a theoretically calculated dielectric recovery to be explained later.

A—175 amperes at 13.8 kv, no shunt, 20 pounds per square inch in the tank, 20-kilocycle timing frequency

B—175 amperes at 13.8 kv, 0.035-microfarad shunt, 20 pounds per square inch in the tank, 20-kilocycle timing frequency



C—1,070 amperes at 13.8 kv, no shunt, 80 pounds per square inch in the tank, 20-kilocycle timing frequency

D—2,260 amperes at 9.2 kv, 0.102-microfarad shunt, 5 pounds per square inch in the tank, 33-kilocycle timing frequency

Figure 4. Cathode-ray oscillograms of arc reignition and extinction voltages

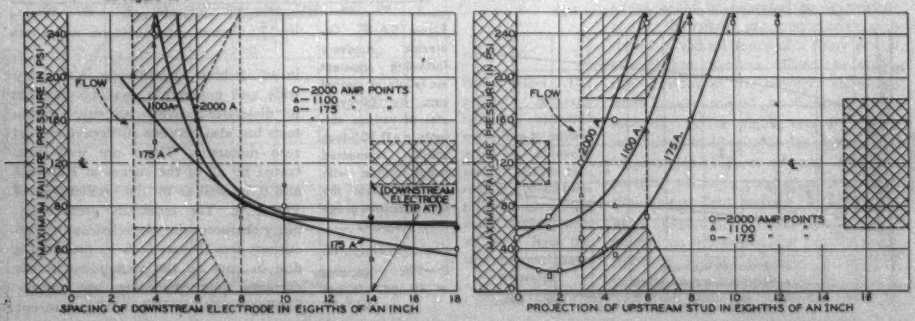
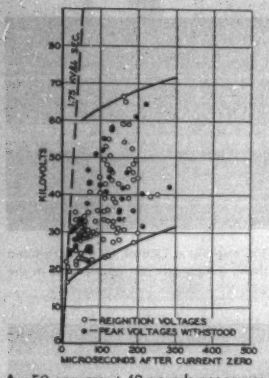
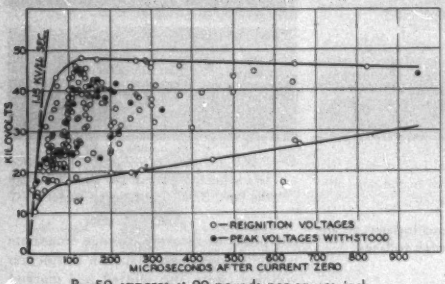

A—(left) Downstream electrode position varied
B—(right) Upstream electrode position varied
MAXIMUM FAILURE PRESSURE IN PSI
FLOW
2000 A
1100 A
175 A
O—2000 AMP POINTS
Δ—1100 " "
□—175 " "
(DOWNSTREAM ELECTRODE TIP AT)
SPACING OF DOWNSTREAM ELECTRODE IN EIGHTHS OF AN INCH
PROJECTION OF UPSTREAM STUD IN EIGHTHS OF AN INCH

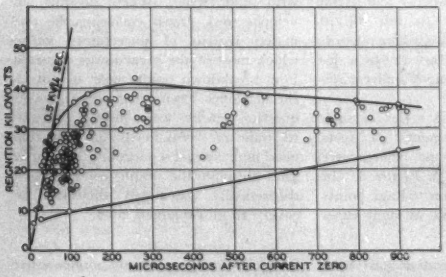
Figure 3. Effect of electrode position on maximum failure pressures at 13.8 kv and various currents for an orifice similar to that of Figure 1A



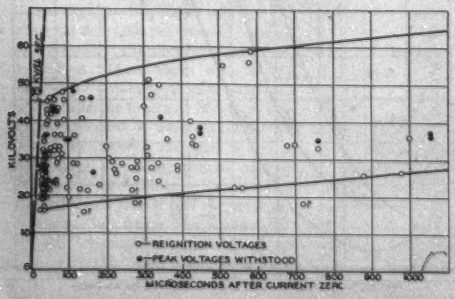
A—50 amperes at 40 pounds per square inch



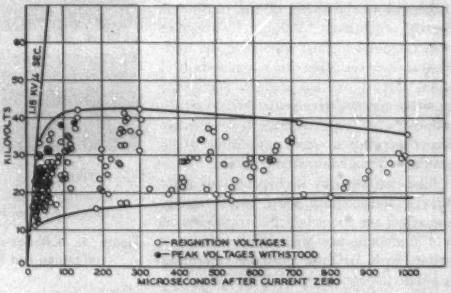
B—50 amperes at 20 pounds per square inch



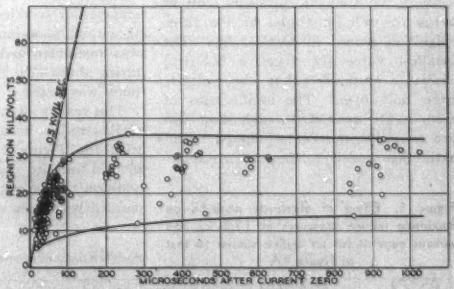
C—50 amperes at 5 pounds per square inch



D—175 amperes at 40 pounds per square inch



E—175 amperes at 20 pounds per square inch



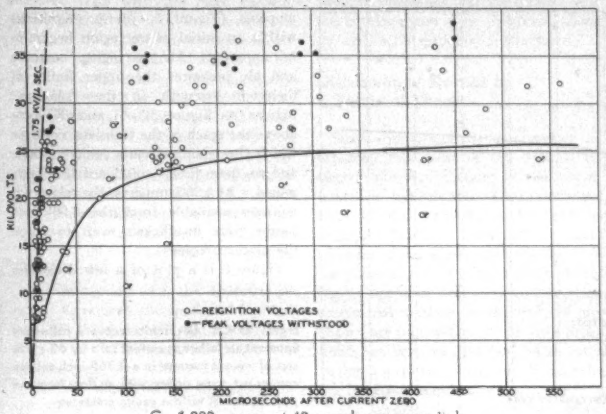
F—175 amperes at 5 pounds per square inch

Figure 5A–F. Dielectric recovery following apparent arc failure at current zero by 60-cycle arcs of various currents in a 0.765-inch solidly connected metal orifice with air flow from the tank at various gauge pressures

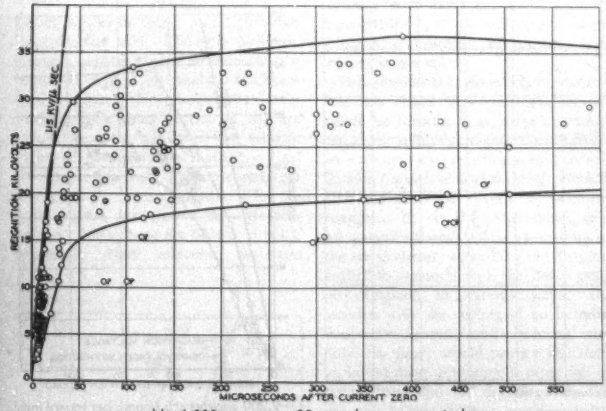
Orifice of Figure 1C

The method of voltage measurement from the oscillograms and of the measurement of the longer times probably involved errors of not more than 10 per cent, but random errors of as much as 50 per cent may easily be present in the measurement of recovery times of the order of 10 or 20 microseconds because of skewing of the oscilloscope axis and uncertainty in locating the often poorly defined arc "current zero" moment. This moment was taken as that at which the course of the arc terminal voltage began to be determined mainly by the circuit rather than by the arc. At low rms currents, this point on the arc terminal voltage record is generally clearly marked by a sudden radical change in slope followed by a smooth oscillation and is believed to be accompanied by a sudden virtual cessation of the arc current, or by an "arc failure." At the higher currents, however, such a transition point becomes much less clear on the oscillograms and also undoubtedly less clear in physical meaning, measurable arc conductivity often persisting up to and beyond the voltage reversal point, which is the only point at which the arc current is certainly known to be zero. It should be kept in mind, therefore, that "time after current zero" plotted in the figures actually means time after apparent arc failure.

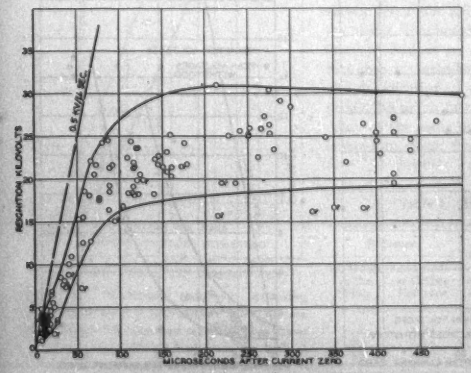
An outstanding feature of all experiments with a-c arcs in general and arcs in an air blast in particular is the very wide and apparently random variation in dielectric recovery, not only between tests but also between successive current zero moments. These are well illustrated by all of the curves in Figures 5 and 6, as well as by the oscillograms of Figure 4. The especially great variability characterizing the reignition of low-current arcs (Figure 5, A–F) probably is due in part to the variability in the currents just preceding arc failure. Similar variations in arc failure current



G—1,200 amperes at 40 pounds per square inch



H—1,200 amperes at 20 pounds per square inch



I—1,200 amperes at 5 pounds per square inch

Figure 5G–I. Dielectric recovery following apparent arc failure at current zero by 60-cycle arcs of various currents in a 0.765-inch solidly connected metal orifice with air flow from the tank at various gauge pressures

Orifice of Figure 1C

were first observed and pointed out by Attwood, Dow, and Krausnick,[7] who also measured and plotted dielectric recovery envelopes similar to those presented here except that they were for low current arcs in still air and in comparatively low voltage circuits.

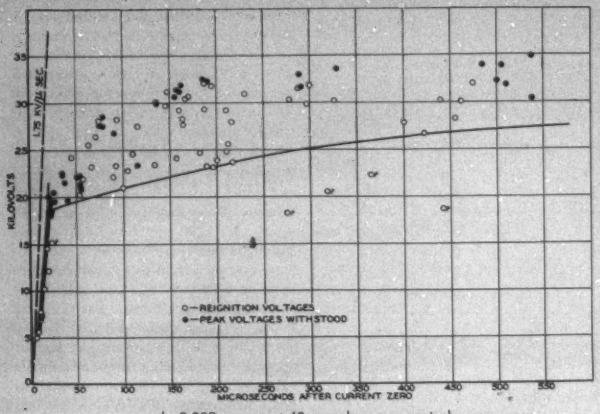
A general survey of the whole array of recovery envelopes and partial envelopes of Figure 5, covering the ranges of currents and pressures: 50, 175, 1,100, 2,200, and 4,200 amperes at 40, 20, and 5 pounds per square inch air tank pressure, reveals certain basic characteristics more or less common to them all. These characteristics are most clearly shown in Figures such as 5I and 5L where a combination of high current and low air pressure resulted in a slower and so more easily followed recovery than in many of the other figures. These envelopes exhibit three separate regions or successive stages of recovery. At very short times (up to 10 or 20 microseconds in these figures) reignition voltages are only moderately higher than the last arc voltages in the preceding half cycle, indicating relatively slight dielectric recovery. After this pause, however, the reignition voltages show a rapid rise with time along loci roughly parallel to the linear rate of rise values indicated by the dotted lines through the origin. This region of rapid recovery at a nearly constant rate is ended, with this orifice, when a rather broad and nearly horizontal breakdown region is reached where the dielectric strength becomes almost independent of time on this few-hundred-microsecond scale. Although showing wide variations and not always so clearly defined, this same pattern seems to characterize the dielectric recovery under all the conditions of current and air pressure covered by these tests. At currents as low as 50 and 175 amperes, the greater natural period of the higher-inductance circuits did not permit exploration of the very short times in which the initial pause might be expected to be evident and so the results are inconclusive with regard to the existence of a delay period at such low currents. Even the rapid-rise portions of the recovery envelopes were largely missed at these currents, especially at the higher pressures. The reignitions at 40 pounds per square inch, for example (Figures 5A and 5D), apparently occurred entirely in the nearly time-independent region. At 1,200 amperes (Figure 5, G–I) most of the early reignitions fell within the rapidly rising recovery region following a possible initial pause. At 2,200 amperes (Figure 5, J–L) and more especially at 4,200

amperes (Figure 5, M–O) reignitions within an initial pause region began to be apparent. At the higher currents and air pressures the upper limits of dielectric strength in the "plateau" regions (see Figures 5G, 5J, and 5K) were above the reach of the transient voltages which the testing circuits could produce and so these limits could not be determined. At 4,200 amperes, the reignition voltages available from the 6,900-volt source were insufficient even to reach the plateau regions.

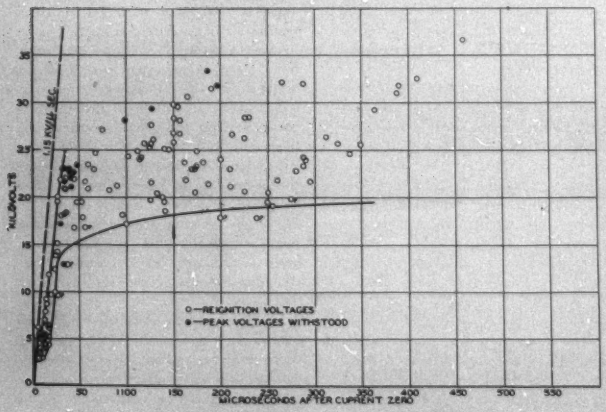
Figure 6 is a plot of a few dielectric

Figure 5J–O. Dielectric recovery following apparent arc failure at current zero by 60-cycle arcs of various currents in a 0.765-inch solidly connected metal orifice with air flow from the tank at various gauge pressures

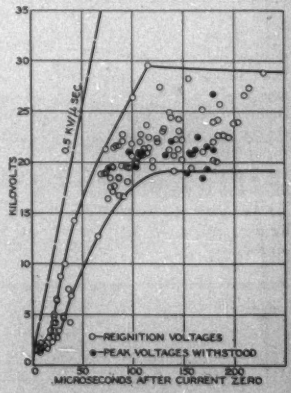
Orifice of Figure 1C



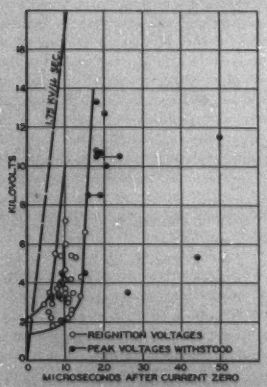
J—2,200 amperes at 40 pounds per square inch



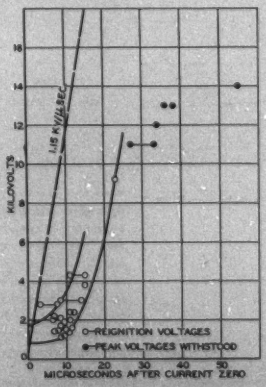
K—2,200 amperes at 20 pounds per square inch



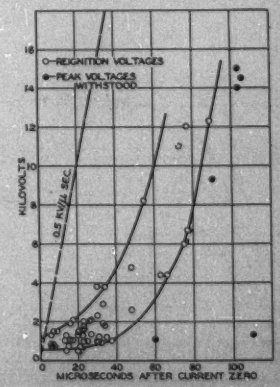
L—2,200 amperes at 5 pounds per square inch



M—4,200 amperes at 40 pounds per square inch



N—4,200 amperes at 20 pounds per square inch



O—4,200 amperes at 5 pounds per square inch

recovery tests with the more efficient insulated and vented orifice arrangement of Figure 1B at the same current and air pressure as the results of Figure 5I for the Figure 1C orifice. The superiority of the Figure 1B orifice is evident in its slightly shorter initial pause, its somewhat more rapid subsequent recovery, and in its much higher plateau voltage limit. This latter is in agreement with the interruption data of Figure 2 where the greatest difference in performance appears at low currents where reignitions occurred only in or near the plateau region.

In conjunction with the dielectric recovery envelopes, the results of Figure 3 now help to locate in space along the orifice axis the different time regions of dielectric recovery. Since the reignitions of the 175-ampere arc in the unshunted test circuit occurred generally in the third, or plateau, time region only, the plateau dielectric strength appears, in Figure 3A, to be fairly well distributed along the flow axis. The early dielectric recovery determining the extinction or reignition of the 1,100- and 2,000-ampere arcs, however, is shown to be quite closely confined to a short portion of the arc channel near the minimum flow section. Figure 3B seems to show that this critical arc length for early dielectric recovery lies nearer to the orifice entrance for the 2,000-ampere arc (faster circuit) than for the 1,100-ampere arc (slower circuit), suggesting that effective dielectric strength makes its first appearance near the entrance and then progresses along the axis in the direction of the flow.

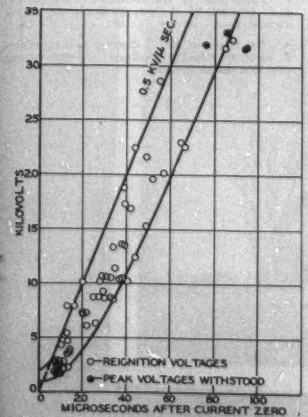


Figure 6. Dielectric recovery following current zero by a 1,100-ampere 60-cycle arc in the Figure 1B insulated metal orifice, lower contact vented, with air flow from the tank at 5 pounds per square inch gauge pressure

Discussion of Results in Terms of Theory

Space limitations do not permit an extended treatment of the various dielectric recovery theories in this paper, but a few possible theoretical interpretations of the foregoing results will be indicated briefly. There still remains so much of vagueness and uncertainty in the physical picture of the rapidly changing a-c arc space near a current zero that precise calculations on the basis of any theory are impossible. Only very broad limits, at best, can be calculated, often so broad as to be valueless in distinguishing between theories.

The apparent initial mean time delays before the beginning of rapid dielectric recovery have been estimated roughly from Figure 5, G–O, and presented in Table I as functions of pressure and rms arc current.

It is possible that these delays, observable only at the higher currents, are, or should be thought of as, mere transition periods of rapidly decreasing but still finite arc conductivity preceding actual arc extinction,[6] which extinction may coincide with the observed upturn in dielectric strength. If, on the other hand, this delay can be thought of as a period when the arc is already essentially out (having negligible conductivity) the delay may be explained in various ways. By analogy with the cooling of an initially uniformly heated solid cylinder, the diffusion theory would predict just such an initial delay preceding a rapid fall of temperature and ion density along the arc axis. Quantitative agreement with the observed time values can also be shown for a one-millimeter arc channel by using Slepian's[4] assumption of a hundred fold or so increase in diffusion rate due to turbulence. If the cooling, and deionization of the last arc filament should be much faster than this, a time delay of the same order can also be calculated to result from the finite rate of acceleration of the surrounding cold and comparatively dense air as it closes in on the low density and so electrically weak arc channel after its temperature and hence its pressure have dropped to a low value. With very rapid cooling, such a momentary associated pressure drop along the arc axis might at least be contributory to the delay in dielectric recovery.

Table I. Time Delays

Pressure		Initial Time Delay in μ sec at Various Currents		
Psi Gauge in the Tank	Abs Atm at Orifice Entrance	1,200 A	2,200 A	4,200 A
5	1.24	13	18	40
20	2.12	6	9	10
40	3.25	5	7	9

The subsequent rapid dielectric recovery also follows from the turbulence enhanced diffusion theory, both qualitatively and quantitatively. After the initial appearance of appreciable dielectric strength, probably at some most favorable point along the arc axis, it may be expected to increase rapidly also by lengthening of the affected region by axial progression of the cooling and recompression process and further by the stretching action of the nonuniform-air velocity near the flow constriction. That such a process may be tied loosely to and so tend to vary with the product of mean air velocity and air pressure (or density) is not surprising. This correspondence is evident in the rather marked agreement (discrepancy two to one or less) between the steep slopes of most of the well defined dielectric recovery envelopes and the slopes of the dotted lines drawn through the origins. These lines were drawn in accordance with the simple displacement theory of Prince[3] on the assumption of a dielectric barrier of sound air formed at "current zero" at the "vena contracta" and growing with the air velocity existing at this point. At first glance, this agreement appears to support the displacement theory, at least in part, but Slepian has shown[4] that the formation of such an assumed sound fluid barrier by simple displacement is physically impossible and the foregoing consideration of the probable diffusion process shows that the agreement can be explained on a basis other than that of simple displacement.

An interesting feature of the plateau dielectric strength values is their relative insensitivity to pressure, especially at the higher currents. The upper and lower limit values at 300 microseconds (well within the plateau region in all cases) have been plotted as a function of the air pressures at the orifice entrance in Figure 7 for different arc current values. The loci of the envelope limits are compared with a dot-and-dash line through the origin representing a linear extrapolation of the observed 60-cycle breakdown voltage at atmospheric pressure with neither air flow nor preliminary arcing. The growing departure with increasing arc current of the plateau breakdown

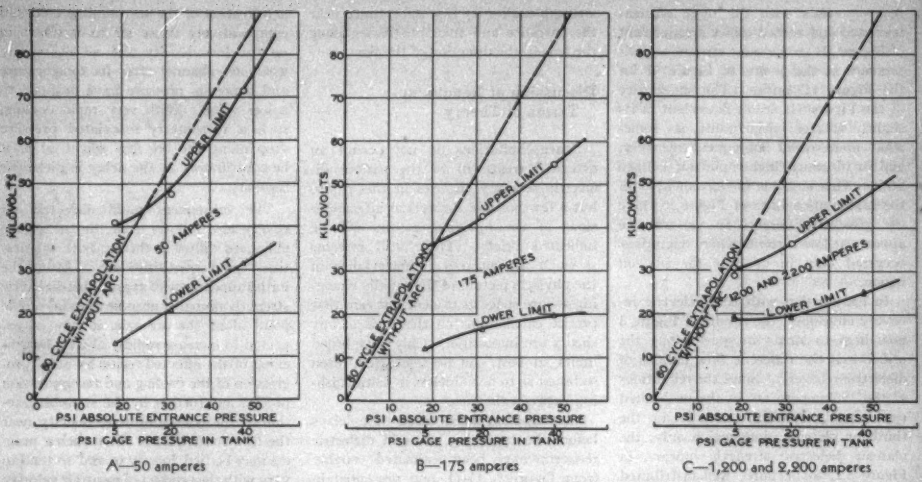


Figure 7. Effect of pressure on dielectric strength recovered 300 microseconds after extinction of arcs of various currents in the Figure 1C orifice

limits from such a no-arc line is particularly hard to explain on the basis of simple displacement of the arc channel by the air flow. It definitely seems to suggest the continuing presence of a still somewhat heated and perhaps partially ionized path along the arc channel after the initially very rapid diffusion has become comparatively slow. The presence in this orifice of a "dead space" of high pressure and low velocity gas at the tip of the upstream contact may be expected to contribute to the slow disappearance of this residual contaminated arc path. The shape of these curves and some incomplete recovery data at higher pressures suggest that these breakdown voltages all increase more rapidly with pressure in the higher pressure range used in practical circuit breakers than they do at the lower pressures covered by these figures.

References

1. Das Schaltproblem der Hochspannungstechnik, III, F. Kesselring, F. Koppelmann. *Archiv. fuer Elektrotechnik*, volume 30, 1936, pages 71–108.

2. The Cross-Air-Blast Circuit Breaker, D. C. Prince, J. A. Henley, W. K. Rankin. AIEE Transactions, volume 59, 1940, September section, pages 510–17.

3. J. Biermanns, Association Suisse des Electriciens *Bulletin*, volume 23, 1932, page 588.

4. Displacement and Diffusion in Fluid-Flow Arc Extinction, J. Slepian. AIEE Transactions, volume 60, 1941, April section, pages 162–7.

5. O. Mayr, *Elektrotechnische Zeitschrift*, volume 53, 1932, pages 75–81, and Association Suisse des Electriciens *Bulletin*, volume 23, 1932, pages 605–10.

6. A Vertical-Flow Outdoor Compressed-Air Breaker, L. R. Ludwig, B. P. Baker. AIEE Transactions, volume 60, 1941, May section, pages 217–22.

7. Reignition of Metallic A-C Arcs in Air, S. S. Attwood, W. C. Dow, W. Krausnick. AIEE Transactions, volume 50, 1931, pages 854–68.

8. The Electric Arc in Circuit Interrupters, J. Slepian. Franklin Institute *Journal*, volume 214, 1932, pages 413–42.

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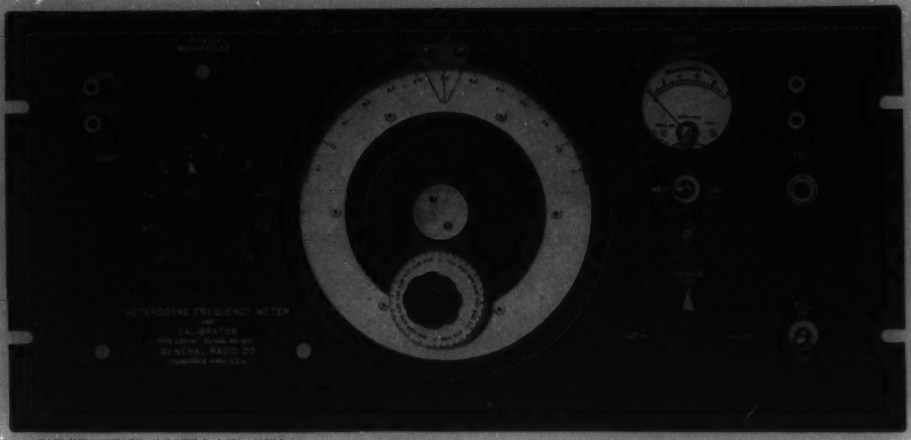

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G.A.F. Carbonyl Iron Powders are obtained by thermal decomposition of iron penta-carbonyl. There are five different grades in production, which are designated as "L," "C," "E," "TH," and "SF" Powder. Each of these five types of iron powder is obtained by special process methods and has its special field of application.

The particles making up the powders "E," "TH," and "SF," are spherical with a characteristic structure of concentric shells. The particles of "L" and "C" are made up of homogenous spheres and agglomerates.

The chemical analysis, the weight-average particle size, the "tap density" (i.e. the density of the powder after a container filled with loose powder has been tapped in a prescribed manner), and the apparent density or bulking factor as determined in a Scott Volumeter are given in the following table for the five different grades:

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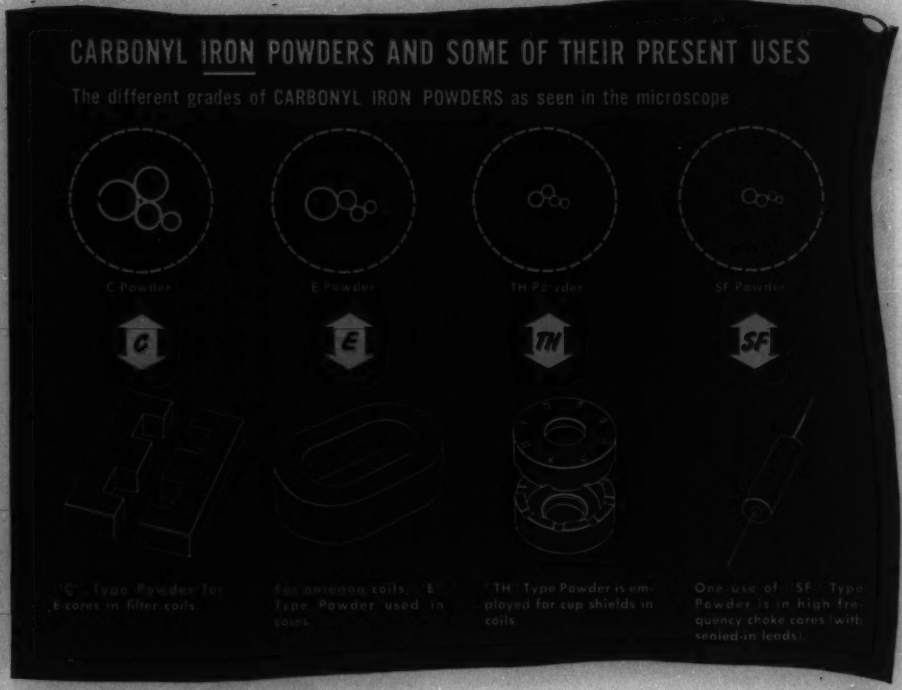
CARBONYL IRON POWDERS AND SOME OF THEIR PRESENT USES
The different grades of CARBONYL IRON POWDERS as seen in the microscope
C Powder
E Powder
TH Powder
SF Powder
C
E
TH
SF
"C" Type Powder for E-cores in filter coils.
For universal coils, "E" Type Powder used in cores.
"TH" Type Powder is employed for cup shields in coils.
One use of "SF" Type Powder is in high frequency choke cores (with sealed-in leads).

Table 2 below gives relative Q values (quality factors) and effective permeabilities for the different grades of carbonyl iron powder. The values given in the table are derived from measurements on straight cylindrical cores placed in simple solenoidal coils. Although the data were not obtained at optimum conditions, the Q values as expressed in percentage of the best core give an indication of the useful frequency ranges for the different powder grades.

"L" and "C" powders are also used as powder metal-

TABLE 2

Carbonyl Iron Grade	Effective Permeability at 1 kc	Relative Quality Factor at 10 kc	100 kc	200 kc	1 Mc	100 Mc
E	4.15	100	98	92	42	8
C	3.45	94	100	96	73	8
L	3.05	91	98	100	82	20
TH	2.97	81	93	98	100	54
SF	2.37	63	71	76	84	100

lurgical material because of their low sintering temperatures, high tensile strengths, and other very desirable qualities. (Sintering begins below 500°C and tensile strengths reach 150,000 psi.)

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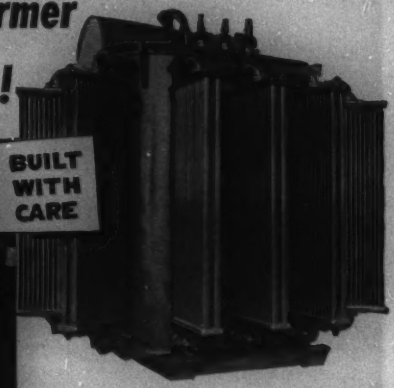

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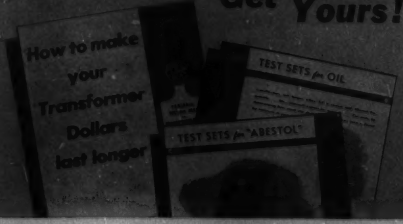

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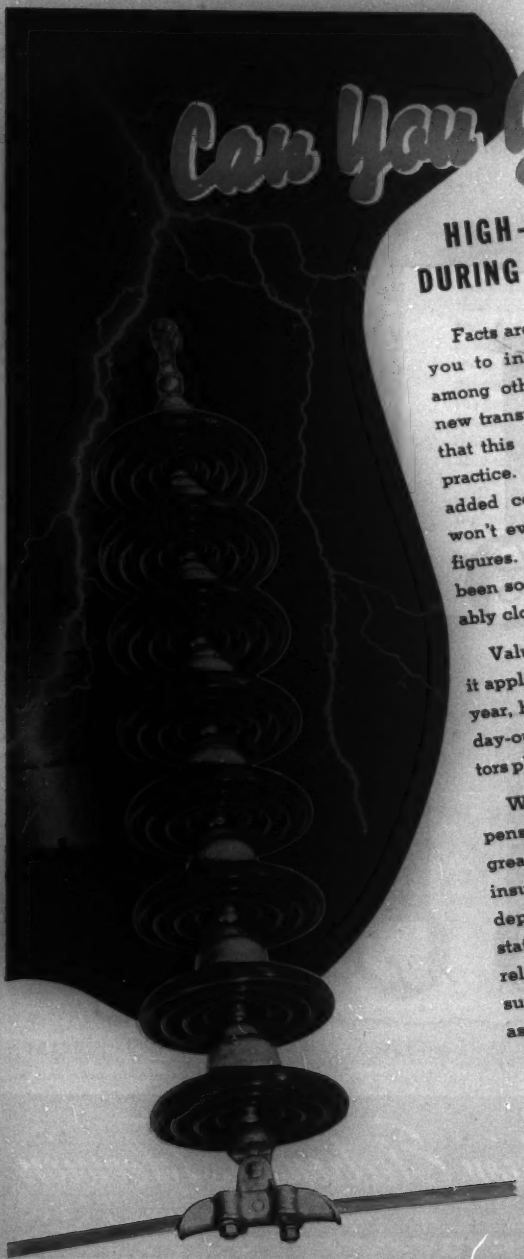

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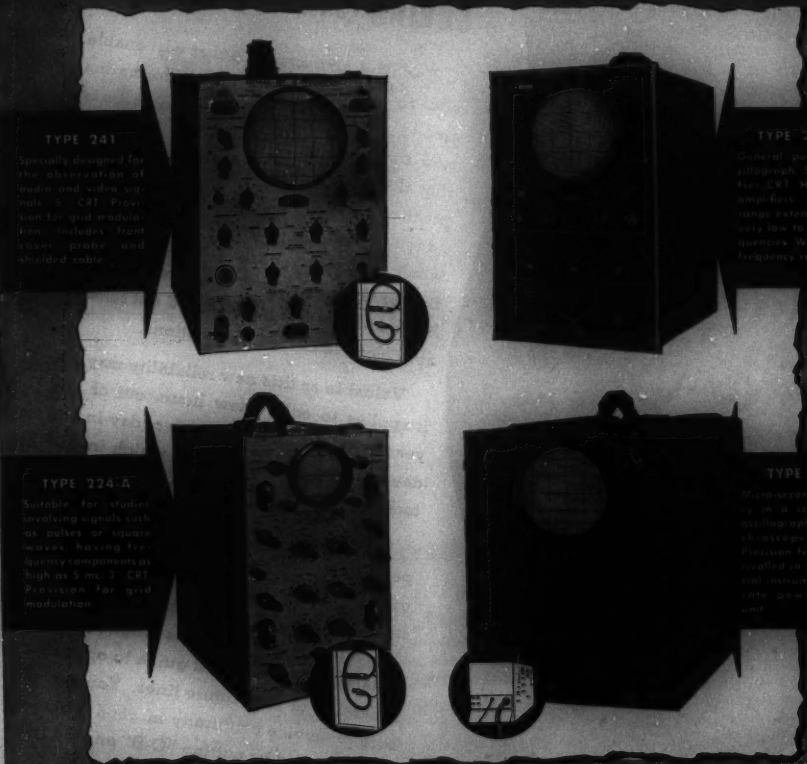

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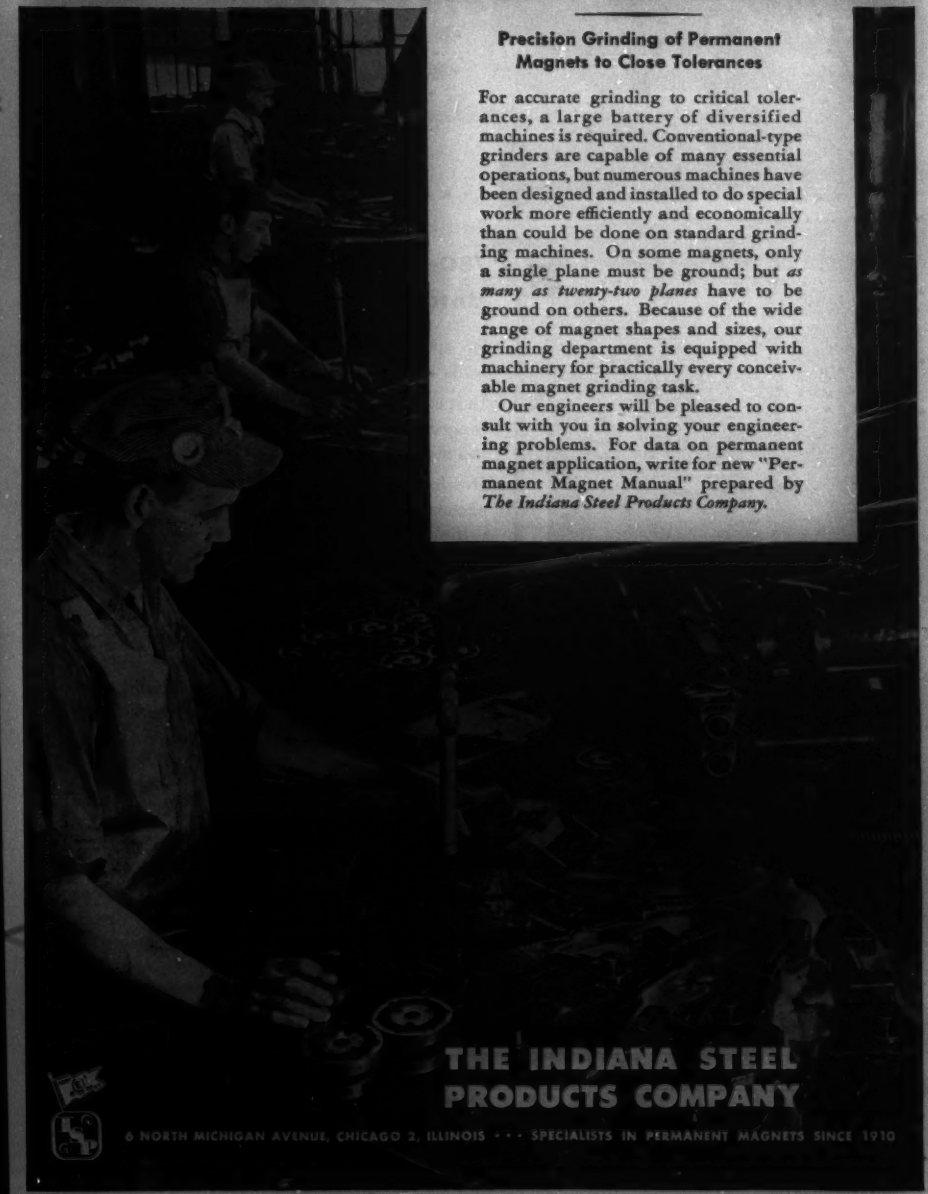

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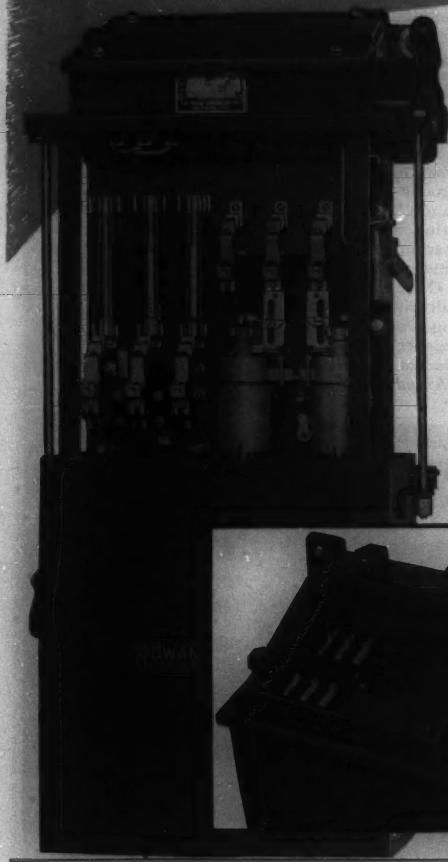

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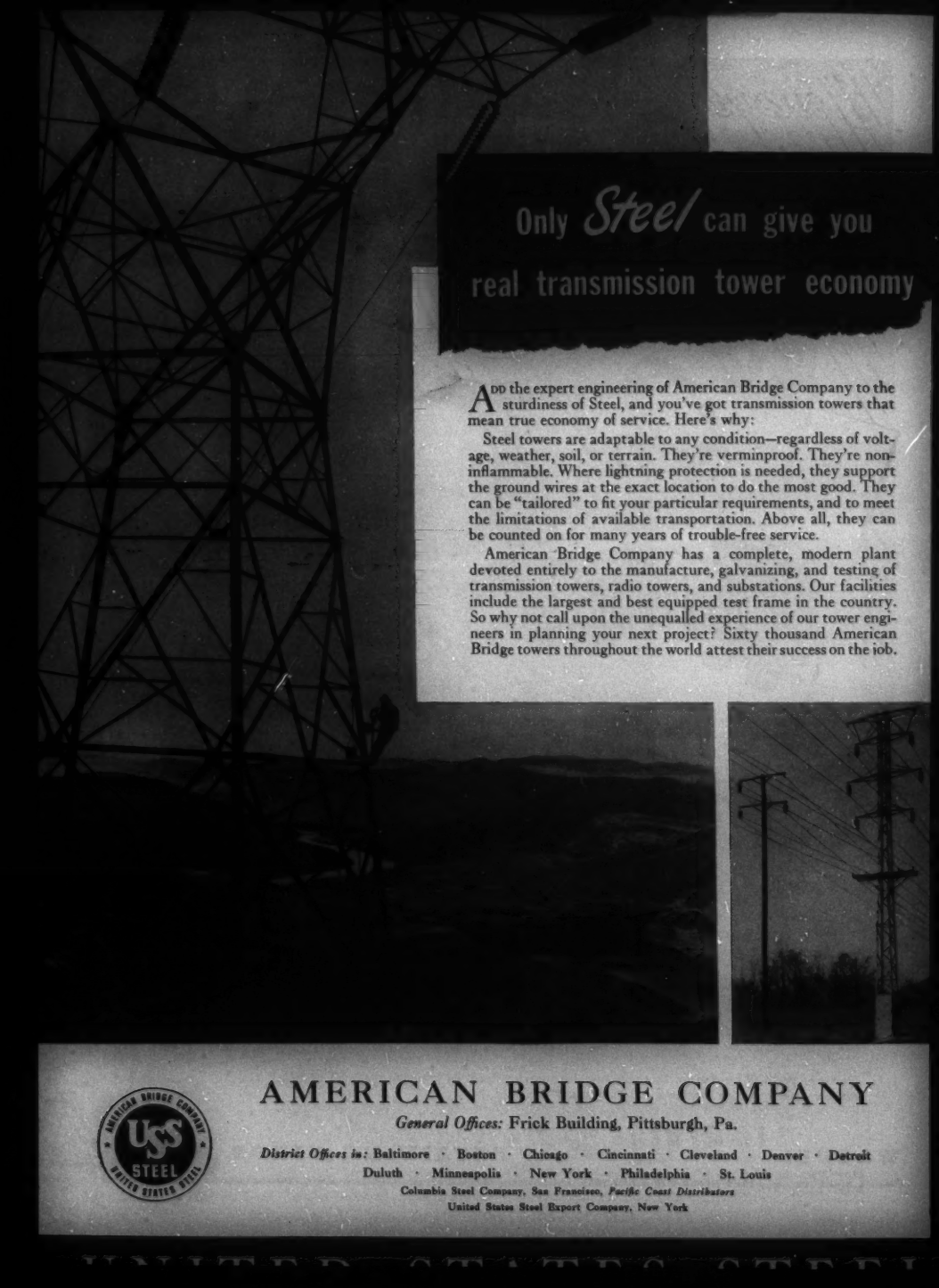

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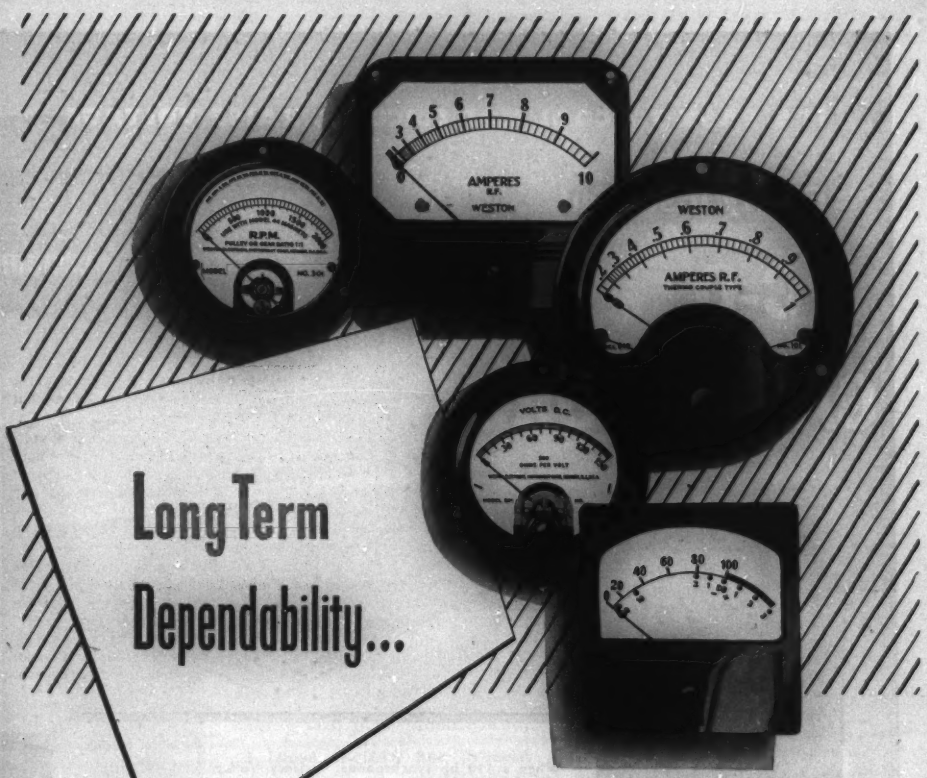

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Bank of three DB Dust-tight Units is easily swung into new universal-type bracket on the wall. Four bolts fasten whole bank firmly on bracket. Complete installation requires only a few minutes interruption of circuits.

Single 7½ kva 230 volt 3 phase 60 cycle enclosed, dust-tight, type DB Capacitor.

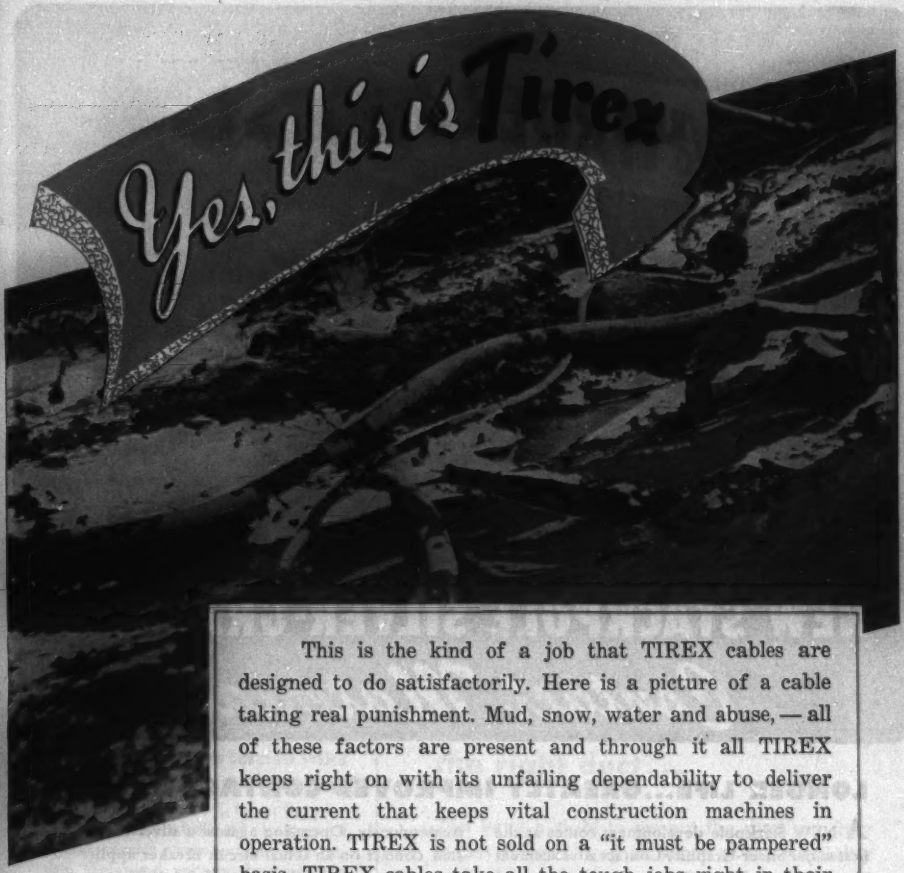
When a 150 hp synchronous motor driving a dc generator was shut down, there was a serious drop in power-factor with overheated circuits and low voltage conditions as a result. The D. O. James Manufacturing Company, Inc., of Chicago, manufacturers of speed reducing transmissions and cut gears, installed 22½ kva banks of 230 volt Cornell-Dubilier Capacitors at several load centers throughout the plant, resulting in greatly increased efficiency. Voltage level was raised, overheating minimized, and current consumption reduced with the same load.

Perhaps there's a suggestion in this for your plant. Let our engineers survey your plant and estimate on your requirements. Investigate the savings possible from a C-D Capacitor installation. Cornell-Dubilier Electric Corporation, South Plainfield, New Jersey.

CORNELL-DUBILIER CAPACITORS

Cornell-Dubilier World's Largest Manufacturers of **Capacitors**

Capacitors for Power-Factor Improvement, Carrier-Current Coupling, Surge Protection



This is the kind of a job that TIREX cables are designed to do satisfactorily. Here is a picture of a cable taking real punishment. Mud, snow, water and abuse, — all of these factors are present and through it all TIREX keeps right on with its unfailing dependability to deliver the current that keeps vital construction machines in operation. TIREX is not sold on a "it must be pampered" basis. TIREX cables take all the tough jobs right in their stride and then ask for more.

TIREX SELENIUM Rubber Armor

The Selenium Rubber Armor which protects the conductors of all TIREX cables is the toughest, most wear-resistant jacket known for wires and cables. The next time you need portable cords or cables that can be depended on be sure you specify TIREX.

Simplex WIRES & CABLES

SIMPLEX WIRE & CABLE CO., 79 SIDNEY ST., CAMBRIDGE 39, MASS.

LONGER LIFE...GREATLY IMPROVED CONTACT DROP

A NEW Stackpole development comes as the first *major* Silver-Graphite Contact advancement since Silver-Graphite Contacts were pioneered years ago by Stackpole and Westinghouse engineers in collaboration.

30% harder than conventional Silver-Graphite types, but with no change in the composition of its ingredients, this new Stackpole material greatly prolongs contact life under short circuit conditions, assures far better contact drop, and improves wearing qualities tremendously. Operating against a silver tungsten contact on an actual circuit breaker application, the material has proved its ability to withstand up to 15,000 amperes under short circuit conditions!

It is an ideal material for a wide variety of circuit breaker, contactor, and relay applications. Composition ranges from 3½% to 10% graphite to meet individual operating conditions, and the contacts can be produced in practically any required shapes or sizes.

STACKPOLE CARBON CO.
ST. MARY'S, PA.
EXPORT: Stackpole Carbon Co.
234 W. 44th St., New York 1, N. Y., U. S. A.

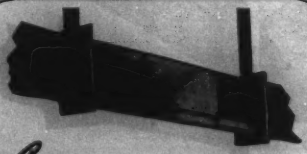
STACKPOLE

MOLDED METAL CONTACTS

Silver-graphite . . . Silver-copper-graphite . . . Gold-graphite . . . Silver-nickel . . . Silver-molybdenum
Silver-tungsten . . . Silver-nickel-molybdenum . . . Silver-nickel-tungsten and dozens of special alloys

Consider these important facts...

...when you're deciding which Duct for your plant!



Compare ...this Square D Saflex Feeder Duct performance with other Duct

Temperature rise 50% lower than for other totally-enclosed busses of equal copper cross-section and rating. Balanced voltage drop of only 1.8 volts per 100 feet.

SAFLEX PLUG-IN DUCT... Running Mate for Saflex Feeder Duct

Permits plugging in machines where and when you want them. Units are easily attached and disconnected. 100% salvage for re-use.

All Feeder and Plug-In Duct is *NOT* pretty much alike...

Performance, not Original Cost, is the prime factor in buying the right duct...

You have a right to expect the duct you buy to pay its own way in terms of the flexibility and increased efficiency it provides. Any good duct will do that. But a careful inspection of SAFLEX DUCT will prove that there's a vast difference in the *degree* of efficiency.

Any duct installation represents a fairly substantial investment . . . substantial enough to justify a thorough comparison before purchase. We not only welcome such a comparison—we urge it.

SQUARE D COMPANY

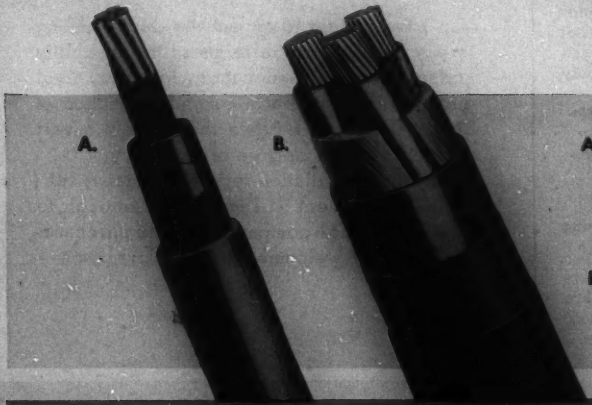
DETROIT • MILWAUKEE • LOS ANGELES

Is your power system

Newly designed equipment and experienced operators apply these improved tapes to the cable insuring proper tension, correct angle of application and proper control of tape position.

Heat test. Precisely controlled ovens subject varnished cambric to aging tests far in excess of normal requirements.

Corona discharge eliminated by conducting rubber. Left—cable insulated with ordinary rubber; note corona. Right—same cable protected by conducting rubber—no corona.



A. VARNISHED CAMBRIC INSULATED LEAD-SHEATHED CABLE with Type PS Shielding. Note use of two semi-conducting tapes—one over the insulation and one between conductor and insulation. PS Shielding prevents spark discharges and corona with attendant ozone formation between insulation and sheath.

B. THREE-CONDUCTOR VARNISHED CAMBRIC CABLE, belted construction with braided cover for dry locations.

Types of Varnished Cambric Cables

- Single-conductor series street lighting cables.
- Multiple-conductor non-leaded and unarmored cables.
- Control cables with combination of different colored braids.
- Single-conductor lead-sheathed cables.
- Single-conductor non-leaded cables.
- Multiple-conductor lead-sheathed or metallic-armored cables.

suffering from *Fatigue?*

Let these husky new Varnished Cambric Cables shoulder the heavy loads

SOME products have been greatly improved during the war. Among them are U·S·S American Varnished Cambric Cables. In many respects, the characteristics of varnished cambric insulation lie between those of rubber and impregnated paper.

The improved type of varnished cambric now employed by the American Steel & Wire Company is highly resistant to heat. It is recommended for operating temperatures up to 85°C. In this respect it is notably superior to rubber. For working voltages of 5000 or less, it may be safely operated at the same maximum temperatures usually recommended for paper insulation.

In dielectric strength, varnished cambric is superior to rubber but not equal to impregnated paper. Compared to rubber, thinner walls of varnished cambric insulation may be employed for a given voltage. Where space is at a premium, new varnished cambric cables, with greater current carrying capacity, can be installed in the *same* space occupied by the old cables.

Cables with varnished cambric insulation are easier to handle and simpler to install than paper insulated cables—the high degree of skill and experience required for jointing and terminating paper cables is not required for varnished cambric cables.

The fact that oil and grease do not injure varnished cambric insulation is another important advantage that recommends it for many purposes. Varnished cambric has less moisture resistance than rubber; and for damp locations, it requires a waterproof covering such as a lead sheath.

For complete information on U·S·S American Varnished Cambric Cables, write for our new catalog.

American Steel & Wire Company

Cleveland, Chicago and New York

Columbia Steel Company, San Francisco, *Pacific Coast Distributors*
Tennessee Coal, Iron & Railroad Company, Birmingham, *Southern Distributors*
United States Steel Export Company, New York

UNITED STATES STEEL

Where American Varnished Cambric Cables offer definite advantages

IN MODERATE OR LOW VOLTAGE INSTALLATIONS where its superior heat resistance permits greater current carrying capacity for a given copper area.

IN POWER PLANTS for general wiring and such applications as insulated bus bars, motor and generator leads, connections for oil switches, transformers and voltage regulators.

IN MANUFACTURING PLANTS, especially where heavy loads must be transmitted for short distances.

U·S·S American Varnished Cambric Cables

Give him a strand he can reason with, handle easily. One he can shape without popping a rib out of place.

That'll be Bethlehem strand. There's nothing cranky about it; nothing balky or stubborn. Naturally, the stronger Bethlehem grades are stiffer than those of lower strength; but in every case, there's a flexible, ductile quality that makes for better handling.

Another good Bethlehem feature is the uniformity of the product. Any reel of Bethlehem strand, selected at random, will show the same careful workmanship as the one you used last week . . . or the one you'll use tomorrow.

Ask for Bethlehem strand in any standard grade. It comes with a bethanized zinc coating of A, B, or C weight—you can select whichever is best for corrosive conditions in your area.

BETHANIZED STRAND

LABORATORY INSTRUMENTS FOR SPEED AND ACCURACY

NEW -hp- DISTORTION ANALYZER

continously variable over entire AF spectrum

OUTSTANDING NEW FEATURES

Covers Audio Spectrum
Measures Noise as Small as 100 Microvolts
Linear r-f Detector
Ball-bearing Frequency Control Dial
High Order of Accuracy and Stability

MODEL 330B

In the Model 330B Distortion Analyzer, the now-famous Hewlett-Packard resistance-tuned circuit is used in conjunction with an amplifier to provide many new and outstanding advantages. Here is an instrument which will measure "total" distortion at *any* frequency from 20 cps to 20,000 cps. Thus for the first time an instrument which covers the audio spectrum is available for distortion measurements. The Model 330B will also make noise measurements of voltages as small as 100 microvolts. A linear r-f dectector makes it possible to measure these characteristics directly from a modulated r-f carrier. This feature, coupled with the convenience, high sensitivity, accuracy, stability, and light weight which are traditional in all -*hp*- instruments, make the Model 330B uniquely valuable for broadcast, laboratory, and production measurement.

USES

The flexibility of the Model 330B leads to a wide number of applications. It may be used to measure the total distortion at any frequency of an audio signal, or of an audio-modulated r-f carrier. It may also be used as a voltmeter for measuring voltage level, power output, amplifier gain, or for any other use for which a high-impedance, wide frequency range, high sensitivity voltmeter is desirable. The frequency selective amplifier can be used as an audio-frequency meter to determine the frequency of an unknown audio signal. The Model 330B may also be used as a high-gain, wide-band, stabilized amplifier, having a maximum gain of 75 db.

This new Model 330B Distortion Analyzer is particularly adapted for use as an all-round measurement device in the broadcast studio and broadcast transmitting room. Speed and ease of operation commend it for laboratory and production testing. Write today for complete data, prices and delivery information on -*hp*'s- newest and finest distortion measuring instrument, the 330B Distortion Analyzer. 1150

NEW MODEL 201B RESISTANCE-TUNED AF OSCILLATOR

In FM and other fields where high fidelity is important, this new -*hp*- Model 201B Audio Frequency Oscillator will meet every requirement for speed, ease of operation, accuracy, and purity of waveform. Outstanding new features include: 3 watts output, distortion less than ½ of 1%, low hum level, new dial with ball-bearing drive, accurate expanded frequency calibration, improved control of output level. Because of its low distortion it is a distinguished companion instrument for the new Model 330B Distortion Analyzer. Write today for complete specifications on this new -*hp*- Resistance-tuned Audio Oscillator.

HEWLETT-PACKARD COMPANY

BOX 1156 • STATION B • PALO ALTO, CALIFORNIA

Audio Frequency Oscillators — *Signal Generators* — *Vacuum Tube Voltmeters*
Noise and Distortion Analyzers — *Wave Analyzers* — *Frequency Meters*
Square Wave Generators — *Frequency Standards* — *Attenuators* — *Electronic Tachometers*

THE Standards of the American Institute of Electrical Engineers now comprise fifty sections on electric machinery and apparatus. They are chiefly devoted to defining terms, conditions, and limits which characterize behavior, with special reference to acceptance tests, and many of them are recognized officially as American Standards.

The Standards available are listed below, together with prices. A discount of 50%, on single copies only, is allowed to Institute members (except as noted). Such discount is not applicable on extra copies unless ordered for other members. A binder (illustrated above) for Standards is available with durable, stiff covers, resembling leather, lettered in gold. Price $1.75 net per binder. Two binders are necessary to hold a complete set of Standards, Reports and Test Codes.

AIEE STANDARDS

(Figures in Parentheses Give Dates of Latest Editions)

No. 1	General Principles Upon Which Temperature Limits are Based in the Rating of Electric Machinery and Apparatus (June 1940)	$ 0.40
1B	Report on Guiding Principles for Specification of Service Conditions (May 1944)	.10
3	Guiding Principles for Selection of Reference Values for Electrical Standards (Oct. 1943)	.30
*4	Measurement of Test Voltage in Dielectric Tests (1942) (ASA C68.1)	.40
*11	Railway Motors (1943) (ASA C36.1)	.50
*16	Electric Railway Control Apparatus (Jan. 1933) (ASA C48)	.40
*17f	Mathematical Symbols (Feb. 1928) (ASA Z10f)	.30
*17gl	Letter Symbols for Electrical Quantities (Nov. 1928) (ASA Z10gl)	.20
**17g5	Graphical Symbols for Electric Traction Including Railway Signaling (Jan. 1934) (ASA Z10g5)	.40
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*36	Storage Batteries (Feb. 1928) (ASA C40)	.20
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601, 602	Preferred Standards and Standard Specification Data for Large 3600-rpm, 3-Phase, 60-Cycle Condensing Steam Turbine Generators (May 1945)	.30
*C8.5, *C8.6, *C8.7	Specifications for Cotton Covered Round Copper Magnet Wire (1936); Specifications for Silk Covered Round Copper Magnet Wire (1936); Specifications for Enameled Round Copper Magnet Wire (1936) (No. C8.5, C8.6 and C8.7 published as one pamphlet)	.30
**C8.11	Code Rubber Insulation for Wire and Cable for General Purposes (1936)	.20
**C8.12	Cotton Braid for Insulated Wire and Cable for General Purposes (1942)	.20
*C8.16	Specifications for Rubber-Insulated Tree Wire (May 1940)	.20
*C8.17	Class AO 30 Percent Rubber Insulation for Wire & Cable for General Purposes (1936)	.20
*C8.18	Weather-Resistant Wire and Cable (URC Type) (1942)	.20
*C8.19	Weather-Resistant Saturants & Finishes for Aerial Rubber-Insulated Wire & Cables (1939)	.20
*C8.20	Heavy-Walled Enameled Round Copper Magnet Wire (1939)	.20
*C19.1	Industrial Control Apparatus (AIEE 15) (1943)	.50
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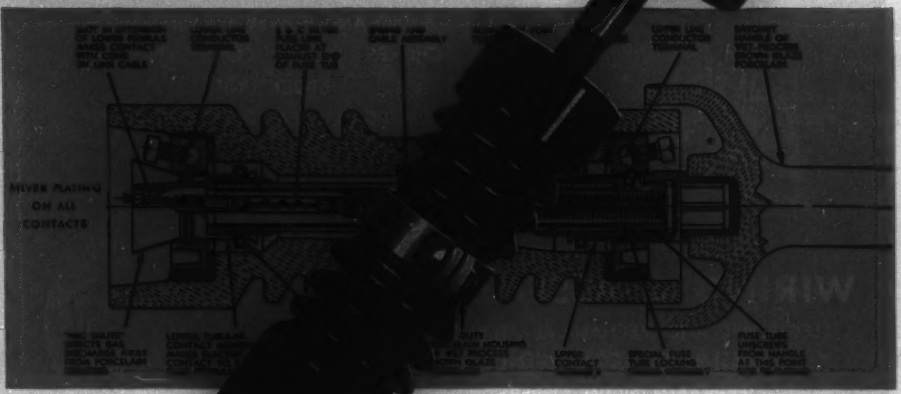
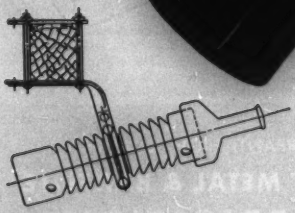
American Institute of Electrical Engineers 33 West 39th Street New York 18, N. Y.

True to S & C Standards

POSITECT assures positive operation and high interrupting capacity





POSITECT *provides these operating advantages:*

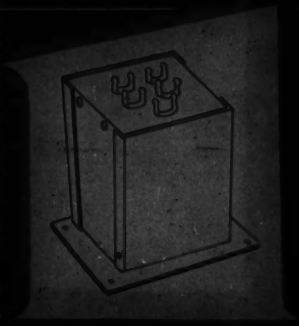
1. Faster and more positive clearing of all faults.
2. Reduced noise and discharge on heavy faults.
3. More dependable clearing of low-value fault currents.
4. Elimination of danger from long, dangling cables after operation.

WITH frequent improvements in construction details . . . 25 years of outstanding dependable service on primary lines in dense metropolitan areas . . . daily convinces more distribution engineers that the unique "Ejector" principle of the S & C Positect Cutout was right from the start . . . that it results in the most positive equipment protection on both low and high current faults . . . while at the same time this cutout is the most simple and convenient to service . . . the definite choice of linemen.

You are certain to benefit by getting all the facts on the Positect Primary Cutout. Ask for long list of satisfied users . . . and Bulletin 215 . . . today!

Schweitzer & Conrad, Inc.
4427 Ravenswood Avenue, Chicago 40, U. S. A.
Represented in Principal Cities (Consult Telephone Directory)
In Canada by Powerlite Devices, Ltd., Toronto, Ont.

Now - 3 FERRANTI DIVISIONS OFFER LOW COST PRODUCTS



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TRANSFORMERS

AUDIO AND POWER TRANSFORMERS
CHOKES • FILTERS • COILS • ETC. ETC.
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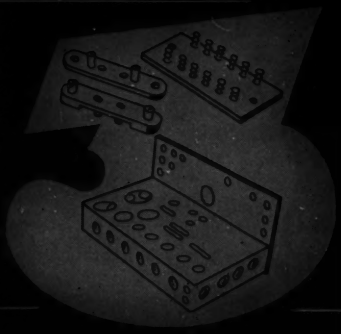

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SHEET METAL & BAKELITE FABRICATION

FROM SHEETS, RODS AND TUBES — PANELS
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CUT — PUNCHED — DRILLED — ENGRAVED
FINISHED TO SUIT YOUR NEEDS

QUALITY — AT LOW COST — PROMPT DELIVERY

FERRANTI ELECTRIC, INC. • RCA BUILDING

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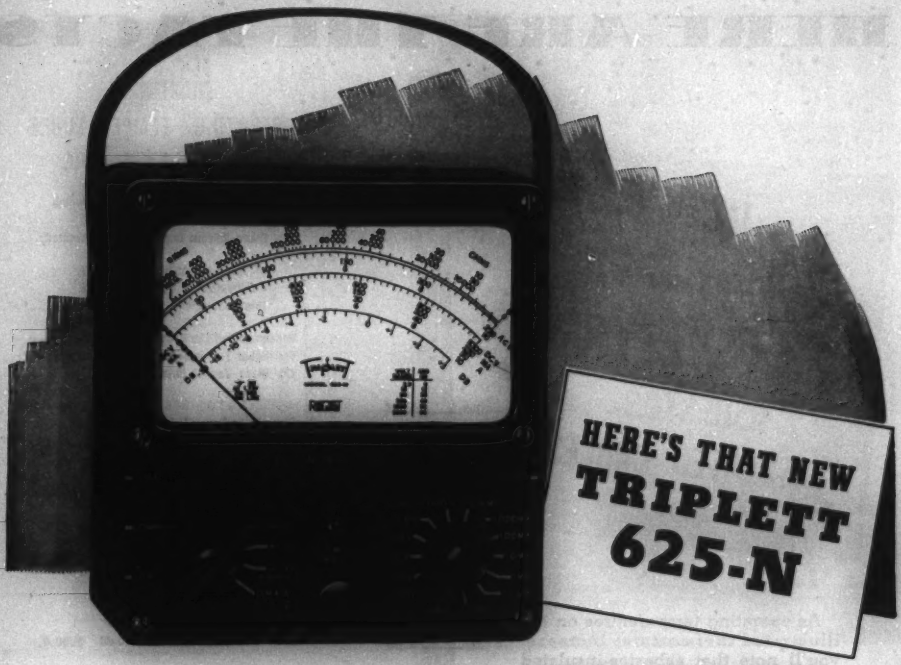
SEND US YOUR SPECIFICATIONS FOR IMMEDIATE ATTENTION



LONG SCALE, WIDE RANGE VOLT-OHM-MILLIAMMETER

DOUBLE SENSITIVITY
D. C. VOLT RANGES
0-1.25-5-25-125-500-2500 Volts, at 20,000 ohms per volt for greater accuracy on Television and other high resistance D.C. circuits.
0-2.5-10-50-250-1000-5000 Volts, at 10,000 ohms per volt.

A. C. VOLT RANGES
0-2.5-10-50-250-1000-5000 Volts, at 10,000 ohms per volt.

OHM-MEGOHMS
0-400 ohms (60 ohms center scale)
0-50,000 ohms (300 ohms center scale)
0-10 megohms (60,000 ohms center scale)

DIRECT READING OUTPUT LEVEL DECIBEL RANGES
−30 to +3, +15, +29, +43, +55, +69 DB

TEMPERATURE COMPENSATED CIRCUIT FOR ALL CURRENT RANGES D.C. MICROAMPERES
0-50 Microamperes, at 250 M.V.

D. C. MILLIAMPERES
0-1-10-100-1000 Milliamperes, at 250 M.V.

D. C. AMPERES
0-10 Amperes, at 250 M.V.

OUTPUT READINGS
Condenser in series with A.C. Volts for output readings.

ATTRACTIVE COMPACT CASE
Size: 2½" x 5½" x 6". A readily portable, completely insulated, black, molded case, with strap handle. A suitable black, leather carrying case (No. 629) also available, with strap handle.

LONG 5" SCALE ARC
For greater reading accuracy on the Triplett RED ● DOT Lifetime Guaranteed meter.

SIMPLIFIED SWITCHING CIRCUIT
Greater ease in changing ranges.

Write for descriptive folder giving full technical details

Precision first ...to last

Triplett

STANDARDS ARE SET BY TRIPLETT

ELECTRICAL INSTRUMENT CO. BLUFFTON, OHIO

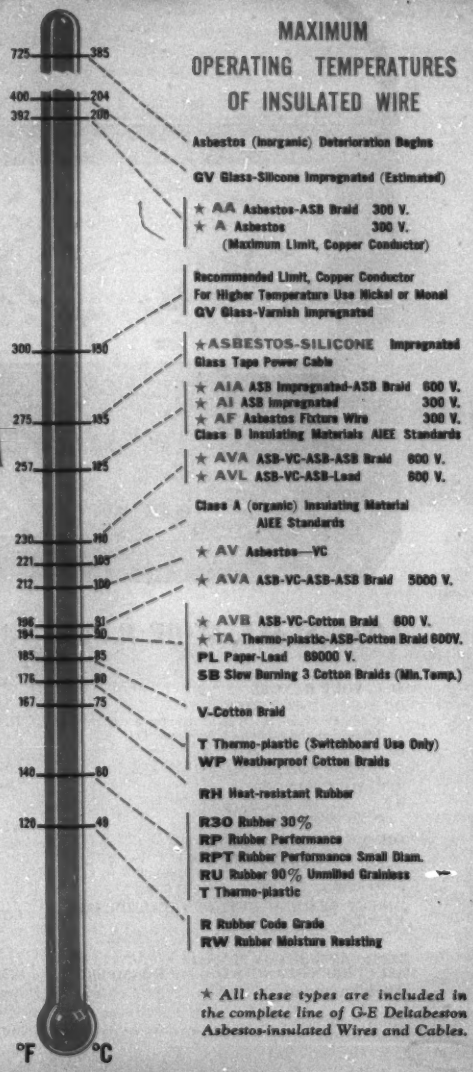
HERE ARE THE FACTS

WHY You Should Use DELTABESTON ASBESTOS-INSULATED CABLES

As operating temperatures on the illustrated thermometer increase, you'll note that asbestos-insulated wires are recommended more frequently than other types. That's why you'll want to investigate Deltabeston for wiring installations exposed to constant high temperatures. These heat-resistant cables are designed for control, lighting and power circuits. Regardless of what type of cable you require, where heat is a problem, Deltabeston fits the job.

• • •

The Deltabeston catalog will help you solve your cable problems. For your free copy, write to Section Y-362-32, Appliance and Merchandise Dept., General Electric Co., Bridgeport, Conn. All Deltabeston Wires and Cables are distributed nationally by Graybar Electric Co., General Electric Supply Corp., and other G-E Merchandise Distributors.



★ *All these types are included in the complete line of G-E Deltabeston Asbestos-insulated Wires and Cables.*

Hear the General Electric radio programs: "The G-E-All Girl Orchestra" Sunday, 10 P.M. EST, NBC. "The World Today" news every weekday 6:45 P.M. EST, CBS. "The G-E House Party" Monday through Friday 4:00 P.M. EST, CBS.

GENERAL ELECTRIC

RCA-892
Water cooled. 14 kw at 1.6 Mc. Mu-30.
RCA-892-R
Forced-air cooled. 10 kw at 1.6 Mc. Mu-30.
RCA-9C21
Water cooled. 100 kw at 5 Mc. Mu-38.
RCA-9C22
Forced-air cooled. 65 kw at 5 Mc. Mu-38.
RCA-889-A
Water cooled. 10 kw at 50 Mc. Mu-21.
RCA-889R-A
Forced-air cooled. 10 kw at 25 Mc. Mu-21.
RCA-7C24
Forced-air cooled. 4 kw at 110 Mc. Mu-25.
RCA-833-A
Natural or forced-air cooled. 1 kw at 30 Mc. Mu-35.
RCA-673
Half-wave mercury rectifier. Super-jumbo base. 1.75 amps at 10,000 v.
RCA-575-A
Half-wave mercury rectifier. Jumbo base. 1.75 amps at 10,000 v.

RCA Tubes for Electronic Heating

These 10 Outstanding Types Offer Wide Latitude in Design

THE 3 water-cooled and 5 forced-air cooled RCA power triodes illustrated range in output from 1 to 100 kw. Higher outputs are readily obtained by using the tubes in push-pull or push-push parallel. Operation at higher than quoted frequencies is practical at slightly reduced ratings. Most types are in the medium-mu class, resulting in good stability under changing load, and have moderate excitation requirements. The forced-air cooled types permit simplified designs having the advantage of complete mobility.

The RCA 575-A and 673 half-wave mercury-vapor rectifier tubes have coated filaments of a special alloy that provide higher thermal efficiency. Zirconium-coated anodes provide increased radiation and are shaped to reduce arc-back and confine glow-discharge bombardment.

The large demand for RCA tubes in broadcasting and industrial applications has resulted in production economies that are passed on to you in the form of lower prices and higher quality.

RCA tube application engineers are ready at all times to co-operate with circuit engineers in the design of radio and electronic equipment using these or other RCA tube types. If they can be of aid, or if you wish additional data on any specific RCA tube types, write RCA, Commercial Engineering Department, Section D-9C, Harrison, N. J.

The Fountainhead of Modern Tube Development is RCA

TUBE DIVISION

RADIO CORPORATION of AMERICA

HARRISON, N. J.

ERIE CERAMICON BY-PASS CONDENSERS

CINCH LOCK-IN, OCTAL and MINIATURE TYPE TUBE SOCKETS

Now for the first time it is possible to increase the efficiency of high frequency circuits by providing the shortest possible electrical path to ground when by-passing tube pins. This is accomplished in the new Plexicon Tube Socket, with silvered ceramic condensers built into the socket, immediately around the tube prongs.

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The Plexicon Tube Socket will be available in Lock-in, Octal and Miniature type sockets, with either center or periphery ground connection. The design is such that any desired combination of tube pins can be by-passed. The maximum capacity of the condenser is 1,000 MMF. The plan view and mounting dimensions of Cinch-Erie Plexicon Tube Sockets are identical with those of standard Cinch sockets.

Samples of the Plexicon Tube Socket will be available shortly in the Lock-in type, Octal and Miniature types. Contact your nearest Erie Resistor or Cinch representative for further information and samples of this outstanding contribution to VHF and UHF design.

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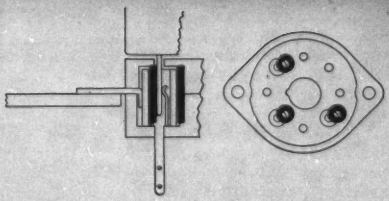
educes set assembly costs.

apacitive coupling effect between by-passed tube in and adjacent pins is reduced by shielding effect outer electrode of condenser.

lexicon sockets are installed exactly the same standard Cinch Lock-in, Octal, and Miniature pe sockets.

op of Cinch-Erie Plexicon Lock-in type socket atches tube base diameter.



The above two schematic diagrams show the basic design principles of Cinch-Erie Plexicon Tube Sockets.

In the plan view, the socket is shown with condensers for by-passing three tube pins. The silvered-ceramic condensers are shown in green.

Note in the side view that standard tube prong clips are used, and that the condenser completely surrounds the tube pin.

Mounting dimensions of the Lock-in type are: 1.312" between center line of mounting holes; chassis hole 1.125" diameter.

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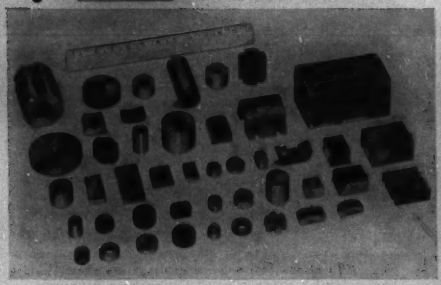

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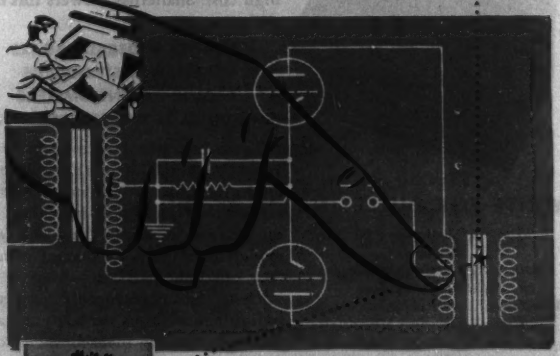

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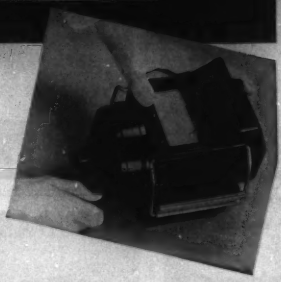

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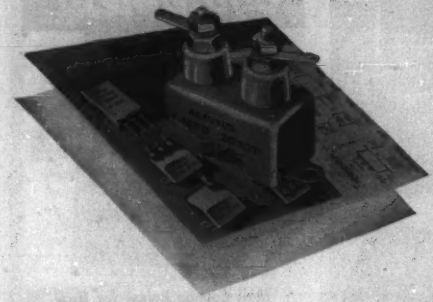

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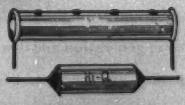

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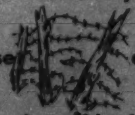
An electric coil never fails without a cause. Isn't it good business, therefore, to try to overcome the cause of trouble —especially premature or recurrent trouble—when the replacement coil is built? By the very act of premature failure, the original coil has proved that it cannot economically face the conditions imposed upon it. We analyze the failure, find what is wrong and prepare a defense  against it. If simply our usual better-than-average coil is needed we supply it. If high ambient temperature is involved, we change construction accordingly. If overloading is unavoidable, we plan for it. If moisture is present, we take that into account. If abrasive dust comes in clouds we guard against it. If the coil is subject to oil or chemical attack we erect a barrier. If mechanical distortion shortens life we prepare for it. If vibration or shock causes damage we reduce their effect. If the original coil cannot cope with changed operating conditions we change specifications to meet the changed needs. And so, time after time, National coils have doubled and tripled the time between outages. That means real saving for someone. How about you? A near-by National field man is ready to help you. Write, wire or phone—now.

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American Transformer Co.	24
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Anaconda Copper Mining Co.	21
Andover-Kent Corp.	49
Arnold Engineering Co.	48
Baldwin Mfg. Co.	2
Bell Telephone Laboratories	23
Bethlehem Steel Co., Inc.	38
Biddle Co., James G.	51
Black & Veatch	55
Barardy Engineering Co.	*
Brown, Christian K.	55
Chicago Transformer Co.	58
Cinch Mfg. Corp.	46, 47
Classified Advertisements	55
Concord Radio Corp.	51
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Corning Glass Works	8, 9
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Ferranti Electric, Inc.	42
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Matthews Corp., W. N.	49
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Okonite Co.	*
Okonite Company, The	5
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Stackpole Carbon Co.	31
Standards—AIEE	40, 54, 56
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Stumpf, George H.	55
Superior Electric Co.	4
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U. S. Steel Corp.	30, 36, 37
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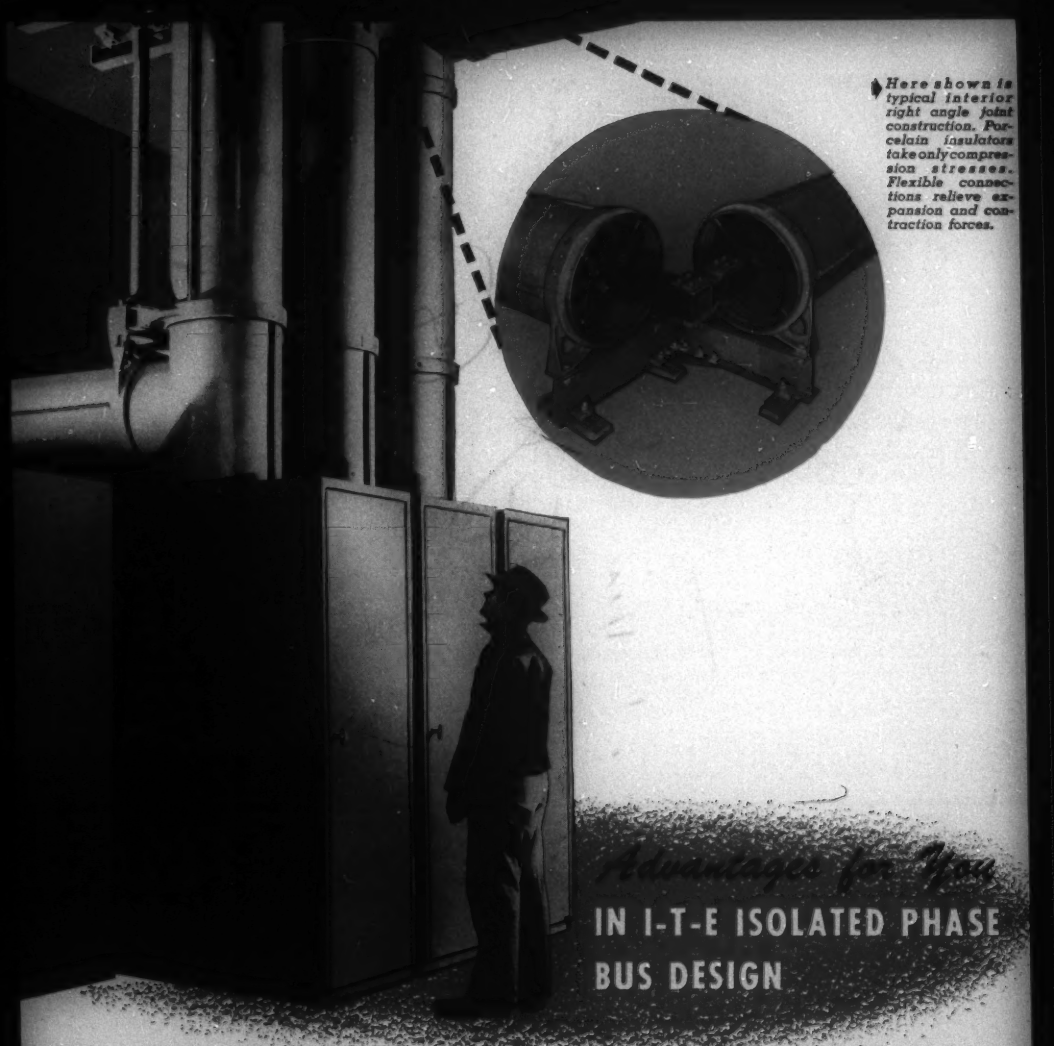

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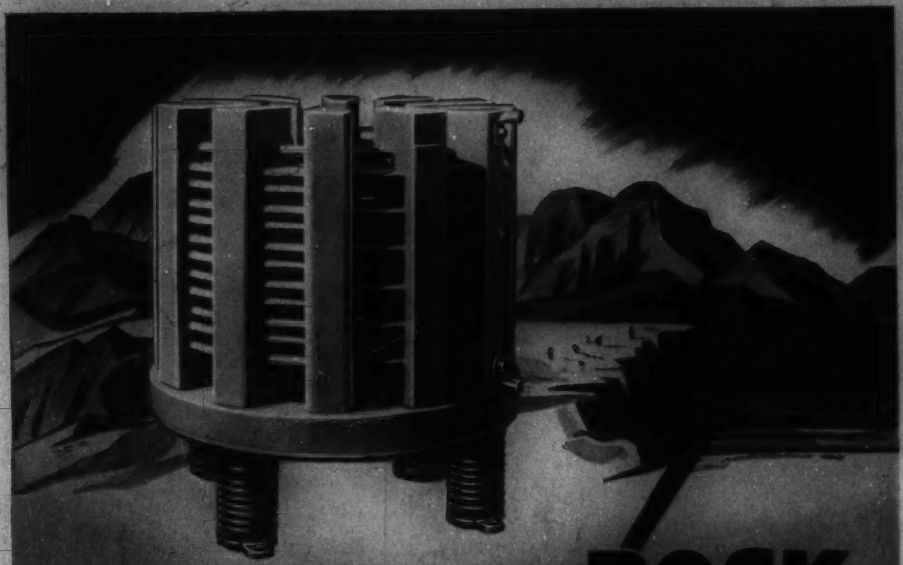

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